



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : <b>C12Q 1/00.</b>		A2	(11) International Publication Number: <b>WO 99/67417</b> (43) International Publication Date: 29 December 1999 (29.12.99)
<p>(21) International Application Number: <b>PCT/US99/14119</b></p> <p>(22) International Filing Date: 23 June 1999 (23.06.99)</p> <p>(30) Priority Data: 60/090,393 23 June 1998 (23.06.98) US</p> <p>(71) Applicant (for all designated States except US): THE UNITED STATES OF AMERICA, represented by THE SECRETARY, DEPARTMENT OF HEALTH AND HUMAN SERVICES (US/US); National Institutes of Health, Office of Technology Transfer, Suite 325, 6011 Executive Boulevard, Rockville, MD 20852 (US).</p> <p>(72) Inventors; and</p> <p>(73) Inventors/Applicants (for US only): ERICKSON, John, W. [US/US]; 5406 Jefferson Boulevard, Frederick, MD 21703 (US). GULNIK, Sergei, V. [US/US]; 8004 Meadowview Drive, Frederick, MD 21702 (US).</p> <p>(74) Agents: GAGALA, Bruce, M. et al.; Leydig, Voit &amp; Mayer, Ltd., Suite 4900, Two Prudential Plaza, 180 North Stetson, Chicago, IL 60601-6780 (US).</p>		<p>(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).</p> <p>Published <i>Without international search report and to be republished upon receipt of that report.</i></p>	
<p>(54) Title: FITNESS ASSAY AND ASSOCIATED METHODS</p> <div style="text-align: center;"> </div> <p>(57) Abstract</p> <p>The present invention provides an assay for determining the biochemical fitness of a biochemical species in a mutant replicating biological entity relative to its predecessor. The present invention further provides a continuous fluorogenic assay for measuring the anti-HIV protease activity of protease inhibitor. The present invention also provides a method of administering a therapeutic compound that reduces the chances of the emergence of drug resistance in therapy. The present invention also provides a compound of formula (I) or R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>5</sup> or R<sup>6</sup> is H, or an optionally substituted and/or heteroatom-bearing alkyl, alkenyl, alkynyl, or cyclic group; Y and/or Z are CH<sub>2</sub>, O, S, SO, SO<sub>2</sub>, amino, amides, carbarnates, ureas, or thiocarbonyl derivatives thereof, optionally substituted with an alkyl, alkenyl, or alkynyl group; n is from 1 to 5; X is a bond, an optionally substituted methylene or ethylene, an amino, O or S; Q is C(O), C(S), or SO<sub>2</sub>; m is from 0 to 6; R<sup>4</sup> is OH, -O (keto), NH<sub>2</sub>, or alkylamino, including esters, amides, and salts thereof; and W is C(O), C(S), S(O), or SO<sub>2</sub>. Optionally, R<sup>5</sup> and R<sup>6</sup>, together with the N-W bond of formula (I), comprise a macrocyclic ring.</p>			

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## FITNESS ASSAY AND ASSOCIATED METHODS

## TECHNICAL FIELD OF THE INVENTION

The present invention relates to a biochemical  
5 fitness assay and related methods.

## BACKGROUND OF THE INVENTION

The development of drug resistance is one of the  
most perplexing challenges in the field of medicine. One  
10 of the most common causes of drug failure in the  
treatment of diseases involving replicating biological  
entities, for example, cancer and infectious diseases, is  
the emergence of drug resistance. One of the most  
dramatic and tragic examples of drug resistance can be  
15 found in connection with the antiviral therapy of  
acquired immune deficiency syndrome (AIDS).

AIDS is a fatal disease, reported cases of which  
have increased dramatically within the past several  
years. Estimates of reported cases in the very near  
20 future also continue to rise dramatically.

The AIDS virus was first identified in 1983. It has  
been known by several names and acronyms. It is the  
third known T-lymphocyte virus (HTLV-III), and it has the  
capacity to replicate within cells of the immune system,  
25 causing profound cell destruction. The AIDS virus is a  
retrovirus, a virus that uses reverse transcriptase  
during replication. This particular retrovirus is also  
known as lymphadenopathy-associated virus (LAV), AIDS-  
related virus (ARV) and, most recently, as human  
30 immunodeficiency virus (HIV). Two distinct families of  
HIV have been described to date, namely HIV-1 and HIV-2.

The acronym HIV will be used herein to refer to HIV viruses generically.

Specifically, HIV is known to exert a profound cytopathic effect on the CD4+ helper/inducer T-cells, 5 thereby severely compromising the immune system. HIV infection also results in neurological deterioration and, ultimately, in the death of the infected individual.

The field of viral chemotherapeutics has developed in response to the need for agents effective against 10 retroviruses, in particular HIV. For example anti-retroviral agents, such as 3'-azido-2',3'-dideoxythymidine (AZT), 2'3'-dideoxycytidine (ddC), and 2'3'-dideoxyinosine (ddI) are known to inhibit reverse transcriptase. There also exist antiviral agents that 15 inhibit transactivator protein. Nucleoside analogs, such as AZT, are currently available for antiviral therapy. Although very useful, the utility of AZT and related compounds is limited by toxicity and insufficient therapeutic indices for fully adequate therapy.

20       Retroviral protease inhibitors also have been identified as a class of anti-retroviral agents. Retroviral protease processes polyprotein precursors into viral structural proteins and replicative enzymes. This processing is essential for the assembly and maturation 25 of fully infectious virions. Accordingly, the design of protease inhibitors remains an important therapeutic goal in the treatment of AIDS.

30       The use of HIV protease inhibitors, in combination with agents that have different antiretroviral mechanisms (e.g., AZT, ddI and ddT), also has been described. For example, synergism against HIV-1 has been observed

between certain C<sub>2</sub> symmetric HIV inhibitors and AZT (Kageyama et al., *Antimicrob. Agents Chemother.*, 36, 926-933 (1992)).

Numerous classes of potent peptidic inhibitors of 5 protease have been designed using the natural cleavage site of the precursor polyproteins as a starting point. These inhibitors typically are peptide substrate analogs in which the scissile P<sub>1</sub>-P<sub>1'</sub> amide bond has been replaced by a non-hydrolyzable isostere with tetrahedral geometry 10 (Moore et al, *Perspect. Drug Dis. Design*, 1, 85 (1993); Tomasselli et al., *Int. J. Chem. Biotechnology*, 6 (1991); Huff, *J. Med. Chem.*, 34, 2305 (1991); Norbeck et al., *Ann. Reports Med. Chem.*, 26, 141 (1991); and Meek, *J. Enzyme Inhibition*, 6, 65 (1992)). Although these 15 inhibitors are effective in preventing the retroviral protease from functioning, the inhibitors suffer from some distinct disadvantages. Generally, peptidomimetics often make poor drugs, due to their potential adverse pharmacological properties, i.e., poor oral absorption, 20 poor stability and rapid metabolism (*Drug Discovery Technologies*, Clark et al., eds., Ellish Horwood, Chichester, England (1990)).

The design of the HIV-1 protease inhibitors based on 25 the transition state mimetic concept has led to the generation of a variety of peptide analogs highly active against viral replication *in vitro* (Erickson et al, *Science*, 249, 527-533 (1990); Kramer et al., *Science*, 231, 1580-1584 (1986); McQuade et al., *Science*, 247, 454-456 (1990); Meek et al., *Nature (London)*, 343, 90-92 30 (1990); and Roberts et al., *Science*, 248, 358-361 (1990)). These active agents contain a non-hydrolyzable,

dipeptidic isostere, such as hydroxyethylene (McQuade et al., *supra*; Meek et al., *Nature (London)*, 343, 90-92 (1990); and Vacca et al., *J. Med. Chem.*, 34, 1225-1228 (1991)) or hydroxyethylamine (Ghosh et al., *Bioorg. Med. Chem. Lett.*, 8, 687-690 (1998); Ghosh et al., *J. Med. Chem.*, 36, 292-295 (1993)); Rich et al., *J. Med. Chem.*, 33, 1285-1288 (1990); and Roberts et al., *Science*, 248, 358-361 (1990)) as an active moiety that mimics the putative transition state of the aspartic protease-  
catalyzed reaction.

Two-fold ( $C_2$ ) symmetric inhibitors of HIV protease represent another class of potent HIV protease inhibitors, which were created by Erickson et al., on the basis of the three-dimensional symmetry of the enzyme active site (Erickson et al. (1990), *supra*). Typically, however, the usefulness of currently available HIV protease inhibitors in the treatment of AIDS has been limited by relatively short plasma half-life, poor oral bioavailability, and the technical difficulty of scale-up synthesis (Meek et al. (1992), *supra*).

In a continuing effort to address the problem of short plasma half-life and poor bioavailability, new HIV protease inhibitors have been identified. For example, HIV protease inhibitors incorporating the 2,5-diamino-3,4-disubstituted-1,6-diphenylhexane isostere are described in Ghosh et al., *Bioorg. Med. Chem. Lett.*, 8, 687-690 (1998) and U.S. Patent Nos. 5,728,718 (Randad et al.). HIV protease inhibitors, which incorporate the hydroxyethylamine isostere, are described in U.S. Patent Nos. 5,502,060 (Thompson et al.), 5,703,076 (Talley et al.), and 5,475,027 (Talley et al.).

Recent studies, however, have revealed the emergence of mutant strains of HIV, in which the protease is resistant to the C<sub>2</sub> symmetric inhibitors (Otto et al., *PNAS USA*, 90, 7543 (1993); Ho et al., *J. Virology*, 68, 5 2016-2020 (1994); and Kaplan et al., *PNAS USA*, 91, 5597-5601 (1994)). In one study, the most abundant mutation found in response to a C<sub>2</sub> symmetry based inhibitor was Arg to Gln at position 8 (R8Q), which strongly affects the S<sub>3</sub>/S<sub>3</sub> subsite of the protease binding domain. In 10 this study, the shortening of the P<sub>3</sub>/P<sub>3</sub> residues resulted in inhibitors that were equipotent towards both wild-type and R8Q mutant proteases (Majer et al., 13th *American Peptide Symposium*, Edmonton, Canada (1993)). Inhibitors have been truncated to P<sub>2</sub>/P<sub>2</sub> without significant loss of 15 activity (Lyle et al., *J. Med. Chem.*, 34, 1230 (1991); and Bone et al., *J. Am. Chem. Soc.*, 113, 9382 (1991)). These results suggest that inhibitors can be truncated and yet maintain the crucial interactions necessary for strong binding. The benefits of such an approach include 20 the elimination of two or more peptide bonds, the reduction of molecular weight, and the diminishment of the potential for recognition by degradative enzymes.

More recently, new mutant strains of HIV have emerged that are resistant to multiple, structurally 25 diverse, experimental and chemotherapeutic retroviral protease inhibitors. Such multidrug-resistant HIV strains are typically found in infected patients, who had undergone treatment with a combination of HIV protease inhibitors or a series of different HIV protease 30 inhibitors. The number of reported cases of patients infected with multidrug-resistant HIV is rising

dramatically. Tragically for these patients, the available options for AIDS chemotherapy and/or HIV management is severely limited or is, otherwise, completely nonexistent.

5. Drug resistance is unfortunately the most common reason for drug failures generally. One of the most dramatic examples of drug failure due to resistance is in HIV therapy. Once HIV resistance is obtained to first-line therapy, the chances of future success are greatly 10 diminished because of the development of multidrug cross resistance. Other diseases involving infectious agents (e.g., viruses, bacteria, protozoa, and prions) or other disease-causing cells (e.g., tumor cells) present similar challenges in that drug resistance is a primary cause of 15 drug failure.

In view of the foregoing problems, there exists a need to determine whether a mutant will be capable of replicating in the presence of a drug. There also exists a need for a method of predicting whether drug resistance 20 is likely to emerge in a disease involving a replicating biological entity. There is also a need for a method of devising a long-term therapeutic regimen that minimizes the likelihood that resistance will occur in a disease involving a replicating biological entity. Moreover, 25 there is a need for a method of preventing or inhibiting the development of drug resistance in such diseases.

The present invention provides such methods. These and other advantages of the present invention, as well as additional inventive features, will be apparent from the 30 description of the invention provided herein.

## BRIEF SUMMARY OF THE INVENTION

The present invention is predicated on the surprising and unexpected discovery that biochemical "vitality," as 5 described below, can be used to determine the biological fitness of a mutant replicating biological entity relative to its predecessor under the selection pressure of an inhibitor. The present invention provides an assay for determining the biochemical fitness of a biochemical 10 target (i.e., a biomolecule having a biochemical function), of a mutant replicating biological entity relative to its predecessor's biochemical target, in the presence of a compound that acts upon the biochemical target. The assay method of the present invention 15 includes obtaining the predecessor, determining the biochemical vitality of the biochemical target of both the predecessor and the mutant in the presence of a compound that acts upon the biochemical target of the predecessor, and comparing the vitality of the mutant's 20 biochemical target relative to the vitality of the predecessor's biochemical target. Where the biochemical vitality of the mutant is greater than the biochemical fitness of the predecessor, the mutant is predicted to be more biologically fit in the presence of the compound. 25 The assay method can thus be used to predict the emergence of drug resistance for a particular replicating biological entity (e.g., a disease-causing cell) in the presence a drug (e.g., an inhibitor). Utilization of the assay in accordance with the present invention permits 30 the administration of an inhibitor or combination of

inhibitors to treat a disease in a way that decreases the likelihood that drug resistance will develop.

The present invention further provides a continuous fluorogenic assay for measuring the anti-HIV protease 5 activity of a protease inhibitor. The continuous fluorogenic assay of the present invention utilizes a substrate of the formula Ala-Arg-Val-Tyr-Phe(NO<sub>2</sub>)<sub>2</sub>-Glu-Ala-Nle-NH<sub>2</sub>. The continuous fluorogenic assay of the present invention is highly sensitive and particularly 10 useful for the prediction of the antiviral inhibitory activity of a compound against mutant HIV.

The present invention further provides a method of administering a therapeutic compound that inhibits a biochemical target of a disease-causing replicating 15 biological entity. The therapeutic compound, when administered in accordance with the method of the present invention, minimizes the chances that the disease-causing entity will develop drug resistance. As such, the method of administering a therapeutic compound in accordance 20 with the present invention improves the chances of long-term success in therapy.

The present method of administering a therapeutic compound involves the identification of at least one mutant replicating biological entity (the mutant) capable 25 of evolving from the disease-causing replicating biological entity (the predecessor). Biochemical fitness is determined by comparing the biochemical vitality of the mutant's biochemical target with the biochemical vitality of the predecessor's biochemical target.

30 Biochemical fitness is determined in the presence of a drug (e.g., an inhibitor). The biochemical vitality of

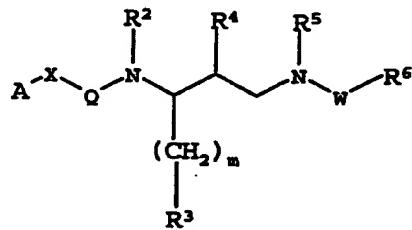
the mutant's biochemical target is compared to biochemical vitality of the predecessor's biochemical target in the presence of the drug. When there are two or more drugs available for treatment, biochemical

5 fitness can be determined for each drug in accordance with the present invention. A therapeutic compound is then administered from among one of the compounds that produces a lower value for biochemical fitness with respect to one or more mutants. Administration of a

10 therapeutic compound producing a lower fitness value for a particular mutant indicates that the predecessor is less likely to develop resistance in the presence of that compound.

The present invention also provides a method of

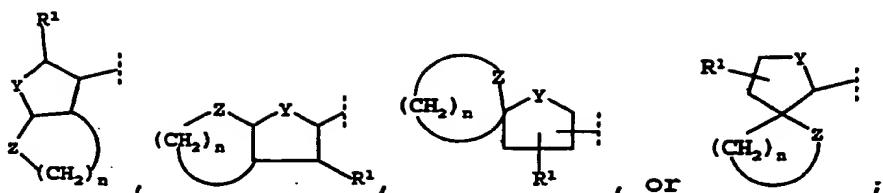
15 preventing the development of drug resistance of HIV in an HIV-infected mammal by the administration of a drug resistance-inhibiting effective amount of a compound of the formula:



20 (I),

or a pharmaceutically acceptable salt, a prodrug, or an ester thereof, or a pharmaceutical composition thereof, wherein:

A is a group of the formula:



$R^1$  is H or an alkyl, an alkenyl, an alkynyl, a cycloalkyl, a cycloalkylalkyl, an aryl, an aralkyl, a heterocycloalkyl, a heterocycloalkylalkyl, a heteroaryl, 5 or a heteroaralkyl radical, which unsubstituted or substituted;

$Y$  and  $Z$  are the same or different and are each selected from the group consisting of  $CH_2$ , O, S,  $SO$ ,  $SO_2$ ,  $NR^8$ ,  $R^8C(O)N$ ,  $R^8C(S)N$ ,  $R^8OC(O)N$ ,  $R^8OC(S)N$ ,  $R^8SC(O)N$ , 10  $R^8R^9NC(O)N$ , and  $R^8R^9NC(S)N$ , wherein  $R^8$  and  $R^9$  are each H, an alkyl, an alkenyl, or an alkynyl;

$n$  is an integer from 1 to 5;  
 $X$  is a covalent bond,  $CHR^{10}$ ,  $CHR^{10}CH_2$ ,  $CH_2CHR^{10}$ , O,  $NR^{10}$ , or S, wherein  $R^{10}$  is H, an alkyl, an alkenyl, or an 15 alkynyl;

$Q$  is  $C(O)$ ,  $C(S)$ , or  $SO_2$ ;  
 $R^2$  is H, an alkyl, an alkenyl, or an alkynyl;  
 $m$  is an integer from 0 to 6;  
 $R^3$  is a cycloalkyl, a heterocycloalkyl, an aryl, or 20 a heteroaryl which is unsubstituted or substituted;  
 $R^4$  is OH, =O (keto),  $NH_2$ , or a derivative thereof;  
 $R^5$  is H, a  $C_1$ - $C_6$  alkyl radical, a  $C_2$ - $C_6$  alkenyl radical, or  $(CH_2)_qR^{14}$ , wherein  $q$  is an integer from 0 to 5, and  $R^{14}$  is a cycloalkyl, a heterocycloalkyl, an aryl, or a 25 heteroaryl which is unsubstituted or substituted;  
 $W$  is  $C(O)$ ,  $C(S)$ ,  $S(O)$ , or  $SO_2$ ; and  
 $R^6$  is a cycloalkyl, heterocycloalkyl, aryl, or heteroaryl which is unsubstituted or substituted.

Optionally, R<sup>5</sup> and R<sup>6</sup>, together with the N-W bond of formula (I), comprise a macrocyclic ring which can contain at least one additional heteroatom in the ring skeleton.

5

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates the synthesis of a particular sulfonamide isostere core of a compound of the present invention.

10

Figure 2 illustrates the synthesis of a bis-tetrahydrofuran ligand and the optical resolution thereof.

15

Fig. 3A illustrates the synthesis of a compound of the present invention via coupling of a bis-tetrahydrofuran ligand to a sulfonamide isostere of the present invention.

20

Fig. 3B illustrates the synthesis of a compound of the present invention via coupling of a bis-tetrahydrofuran ligand to a sulfonamide isostere of the present invention.

25

Figure 4 illustrates generally the present method of synthesizing a compound of the present invention.

30

Figures 5A-5D illustrate the structures of particular compounds that were tested against various drug resistant HIV mutants.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is predicated on the surprising and unexpected discovery to that the "vitality" of a biochemical target of a mutant replicating biological entity relative to that of its predecessor's biochemical target can be used to predict the biological fitness of the mutant under the selection pressure of an inhibitor of the biochemical target. The "vitality" of a biochemical target of a mutant replicating biological entity relative to the "vitality" of its predecessor's biochemical target is defined herein as the "biochemical fitness."

"Vitality" as utilized herein describes the ability of a particular biomolecular "target" (i.e., a biochemical species intended to be inhibited by a particular inhibitor) to perform its biochemical function in the presence of the inhibitor. Biochemical vitality is a function of at least two variables: the ability of a particular inhibitor to inhibit a biochemical target of the replicating biological entity in question, and the ability of the cell's biochemical target to inherently perform its biochemical function (irrespective of an inhibitor). Biochemical vitality also can include other factors that effect the ability of a biochemical target to perform its biochemical function in the presence of the inhibitor.

The biochemical target in question can include, for example, a biochemical species with one or more known or unknown biological functions. The biochemical target can be, for example, a biochemical species having one or more specific biochemical function, or it can be a biochemical species that effects or influences a biochemical function

directly or indirectly. Suitable biochemical targets include, for example, enzymes, proteins, oligomers, receptors, and the like. Suitable enzymes include, for example, reverse transcriptases, proteases (e.g.,

5 retroviral proteases, plasmepsins, and the like), methylases, oxidases, esterases, acyl transferases, and the like. Suitable enzymes also include, for example, viral and non-viral helicases, topoisomerases, DNA gyrases, DNA and RNA polymerases, parasite-encoded

10 proteases, and the like.

Suitable proteins include, for example, proteins that incorporate a conformational change as a major functional requirement, and the like. Examples of such proteins include HIV gp41 and other fusogenic viral

15 proteins and peptides, topoisomerases, and all DNA enzymes, and the like.

Suitable oligomers include, for example, oligomers that require oligomerization in order to perform their biochemical function. Examples of such oligomers include

20 HIV protease, retroviral fusion proteins, peptides, HIV gp 41, viral and non-viral membrane fusion proteins, tumor suppressor proteins (e.g., p53, and the like) prions, ribosomes, and the like.

The ability of a particular inhibitor to inhibit a

25 biochemical target of a particular replicating biological entity can be determined by any suitable method and/or can be obtained from any suitable source. The ability of a particular inhibitor to inhibit a biochemical function of a replicating biological entity can be determined, for

30 example, on the basis of a measurable property, or a measurable relationship of properties, that correlate

with the ability of the inhibitor to inhibit the target. Suitable methods for determining the ability of the inhibitor to inhibit the target include, for example, assays, and the like. In some instances, the ability of 5 the inhibitor to inhibit the target can be obtained from one or more suitable sources, for example, assay data from a database, a textbook, or the literature.

When the biochemical target is a protein, the ability of an inhibitor to inhibit the protein can be 10 determined, for example, by obtaining the equilibrium dissociation constant ( $K_d$ ) of drug binding to the target where drug binding interferes with the function of the protein.

When the biochemical target is an enzyme, the 15 ability of an inhibitor to inhibit the enzyme can be determined, for example, by obtaining the inhibition constant ( $K_{inh}$ ), or the like. The inhibition constant can be in terms of drug inhibition constant for the effect of the drug on substrate catalysis (e.g.,  $K_i$ ) or 20 dissociation constant for drug binding (e.g.,  $K_d$ ) where drug binding correlates with inhibition of enzyme function.

When the biochemical target is an oligomer, the ability of an inhibitor to inhibit the oligomer can be 25 determined, for example, by obtaining the equilibrium dissociation constant ( $K_d$ ) for drug binding where drug binding interferes with oligomerization of the target.

Where the biochemical target is a protein that requires a conformational change for its function, the 30 ability of an inhibitor to inhibit the conformational change can be determined, for example, by obtaining the

equilibrium dissociation constant ( $K_d$ ) for drug binding where drug binding interferes with the conformational change of the target.

When the biochemical target is a protein that is required to bind to a ligand, macromolecule, or macromolecular complex to perform its biochemical function, the ability of an inhibitor to inhibit the protein function can be determined by obtaining the equilibrium dissociation constant ( $K_d$ ) for drug binding where drug binding interferes with ligand binding, macromolecule binding, or macromolecular complex binding.

When the biochemical target is a nucleic acid binding protein, the ability of an inhibitor to inhibit the nucleic acid binding protein's function can be determined by obtaining the equilibrium dissociation constant ( $K_d$ ) for drug binding where drug binding interferes with nucleic acid binding.

Vitality also is a function of the biochemical target's ability to inherently perform its biochemical function (irrespective of an inhibitor). The biochemical target's ability to inherently perform its biochemical function can be determined by any suitable method and/or can be obtained from any suitable source. The biochemical target's ability to inherently perform its biochemical function can be determined, for example, on the basis of a measurable property, or measurable relationship of properties, that correlate with the ability of the biochemical target's ability to inherently perform its biochemical function. Suitable methods for determining the biochemical target's ability to inherently perform its biochemical function include, for

example, biochemical assays, and the like. In some instances, the ability of a cell's biochemical target to inherently perform its biochemical function can be obtained from one or more suitable sources, for example, 5 assay data from a database, a textbook, or the literature.

When the biochemical target is an enzyme, the ability of the enzyme to inherently perform its biochemical function can be determined, for example, by 10 determining the catalytic efficiency of the enzyme. For example, the catalytic efficiency for enzymes that exhibit Michaelis-Menten kinetics can be determined by obtaining the  $k_{cat}/K_m$  ratio, or by a similar method, wherein  $k_{cat}$  is the catalytic rate and  $K_m$  is the Michaelis 15 constant.

When the biochemical target is a protein, the ability of the protein to inherently perform its biochemical function can be determined, for example, by obtaining the equilibrium constant ( $K_{eq}$ ) for the 20 biochemical function of the protein, or the like.

When the biochemical target is an oligomer, the ability of an inhibitor to perform its biological function can be determined, for example, by obtaining the equilibrium constant ( $K_{eq}$ ) that is associated with 25 oligomerization.

Where the biochemical target is a protein that requires a conformational change for its function, the ability of the target to perform its function can be determined, for example, by obtaining the equilibrium 30 constant ( $K_{eq}$ ) associated with conformational change.

When the biochemical target is a protein that is required to bind to a ligand to perform its function, the ability of the target to perform its function can be determined, for example, by obtaining the equilibrium 5 dissociation constant ( $K_d$ ) for ligand binding.

When the biochemical target is a nucleic acid binding protein, the ability of an inhibitor to perform its function can be determined by obtaining the equilibrium dissociation constant ( $K_d$ ) for nucleic acid 10 binding.

It will be appreciated that vitality also can be a function of other factors that effect the ability of a biochemical target to perform its biochemical function in the presence of the inhibitor. If the biochemical target 15 is a dimeric species, for example, other factors that influence biochemical vitality might include the ability of the species to dimerize in the presence and/or in the absence of the inhibitor. If, by way of example, a mutation causes the dimerization rate to become a factor 20 in the biochemical function of the biochemical target of the mutant relative to its predecessor's, then dimerization rate can be included in the vitality determination.

The biochemical vitalities of a mutant replicating 25 biological entity and its predecessor, when compared, describes the biochemical fitness of the target of the mutant cell. In keeping with the invention, it has been found that the biochemical fitness relates to the biological fitness of the mutant in the presence of the 30 inhibitor. When the value for the biochemical vitality of the target of the mutant exceeds the value for the

biochemical vitality of the target of a predecessor of the mutant, the target of the mutant has greater biochemical fitness in the presence of the inhibitor. In such cases, the mutant replicating biological entity is 5 favored over the predecessor and resistance to the inhibitor that is used to treat the predecessor is likely to develop.

Biochemical vitality can be determined in many different ways that suitably relate the various factors 10 relating to the biochemical vitality of the target. For example, a mathematical function may be used to relate the various factors. By way of illustration, when the biochemical target is an enzyme, the vitality can be determined as a function of  $K_{inh}$  (e.g.,  $K_i$  or  $K_d$ ) and 15 enzymatic or catalytic efficiency (e.g.,  $K_{cat}/K_m$ ). Vitality can be determined as the product of  $K_{inh}$  and enzymatic efficiency, for example,  $(K_{inh}) \times$  (catalytic efficiency), or  $(K_i) \times$  (catalytic efficiency) or  $(K_d)$  (catalytic efficiency). Alternatively, vitality can 20 be determined, for example, as the log of the product of  $K_{inh}$  and enzymatic efficiency, for example,  $\log[(K_{inh}) \times$  (catalytic efficiency)], or  $\log[(K_i) \times$  (catalytic efficiency)] or  $\log[(K_d) \times$  (catalytic efficiency)]. Similarly, for enzymes that exhibit Michaelis-Menten 25 kinetics, vitality can be determined as a function of  $K_{inh}$  (e.g.,  $K_i$  or  $K_d$ ) and the  $k_{cat}/K_m$  ratio. For example, vitality can be determined as the product of  $K_{inh}$  and  $k_{cat}/K_m$ , e.g.,  $(K_{inh}) \times (k_{cat}/K_m)$ , wherein  $K_{inh}$  is  $K_i$  or  $K_d$ . Alternatively, vitality can be determined, for example, 30 as the log of the product of  $K_{inh}$  and  $k_{cat}/K_m$ , e.g.,  $\log[(K_{inh}) \times (k_{cat}/K_m)]$ , wherein  $K_{inh}$  is  $K_i$  or  $K_d$ . In a

preferred embodiment, the biochemical target is an enzyme and the vitality is  $(K_i) \times (k_{cat}/K_m)$ , or  $\log[(K_i) \times (k_{cat}/K_m)]$ .

"Fitness," unless otherwise indicated, means

5 biochemical fitness. "Biochemical fitness" as utilized herein is a value that represents the vitality of a biochemical target of a mutant replicating biological entity relative to the vitality the biochemical target of its predecessor. Biochemical fitness is determined by

10 comparing the vitality of a biochemical target of a mutant replicating biological entity relative to that of its predecessor. Any suitable comparison of the vitality of a biochemical target of a mutant replicating biological entity relative to that of its predecessor can be used in

15 the determination of fitness. For example, biochemical fitness can be determined as the difference between the biochemical vitality of a biochemical target of a predecessor (biochemical vitality<sub>pred</sub>) and the biochemical vitality of the biochemical target of a particular mutant

20 replicating biological entity that can evolve from the predecessor (biochemical vitality<sub>mut</sub>), e.g., (biochemical vitality<sub>mut</sub>) - (biochemical vitality<sub>pred</sub>). If biochemical fitness is determined on the basis of this difference, then a positive value indicates that the mutant has a

25 higher fitness relative to its predecessor in the presence of the inhibitor, whereas a negative value indicates that the mutant is less fit relative to its predecessor. A value of zero indicates that the fitness of the mutant and the predecessor are equal. A higher positive value

30 indicates a greater chance that resistance to the inhibitor will emerge, whereas a higher negative value

indicates a lower chance that resistance to the inhibitor will emerge.

Alternatively, and preferably, fitness can be determined as the quotient of two biochemical vitalities,

5 for example, as the quotient of a biochemical target of a particular mutant replicating biological entity and the biochemical vitality of the biochemical target of a predecessor, e.g.,

$$\text{fitness} = \frac{\text{vitality}_{\text{mut}}}{\text{vitality}_{\text{pred}}}.$$

10 If fitness is determined on the basis of this quotient, then a value greater than one indicates that the mutant has a higher fitness relative to its predecessor, in the presence of the inhibitor. A value of one indicates that the fitness of the mutant and the predecessor are equal.

15 A value less than one indicates that the mutant is less fit relative to its predecessor. A higher value indicates a greater chance that resistance to the inhibitor/drug will emerge, whereas a lower value indicates a lower chance that resistance to the inhibitor/drug will emerge.

20 A value less than one indicates that the mutant will not emerge in the presence of the inhibitor/drug.

Alternatively, fitness can be determined as the log of the quotient of two biochemical vitalities, for example, as the log of the quotient of a biochemical target of a particular mutant replicating biological entity and the biochemical vitality of the biochemical target of a predecessor, e.g.,

$$\text{fitness} = \log \left[ \frac{\text{vitality}_{\text{mut}}}{\text{vitality}_{\text{pred}}} \right].$$

If fitness is determined on the basis of this log, then a value greater than zero indicates that the mutant has a higher fitness relative to its predecessor, in the presence of the inhibitor. A negative value indicates 5 that the mutant is less fit relative to its predecessor. A value of zero indicates that the fitness of the mutant and the predecessor are equal. A higher positive value indicates a greater chance that resistance to the inhibitor/drug will emerge, whereas a lower positive 10 value indicates a lower chance that resistance to the inhibitor/drug will emerge. A negative value indicates that the mutant will not emerge in the presence of the inhibitor/drug.

Fitness can be determined in the presence of any 15 suitable compound that inhibits a biochemical target from performing its biological function. The inhibitor, for example, can be a compound that inhibits an enzyme. Suitable enzyme inhibitors include, for example, protease inhibitors, reverse transcriptase inhibitors, DNA 20 polymerase inhibitors, methylase inhibitors, oxidase inhibitors, esterase inhibitors, acyl transferase inhibitors, and the like.

Suitable protease inhibitors include, for example, viral protease inhibitors, plasmepsin inhibitors, and 25 cathepsin D inhibitors. In a preferred embodiment, the inhibitor is a viral protease inhibitor, more preferably a retroviral protease inhibitor, still more preferably an HIV-1 or an HIV-2 protease inhibitor, and most preferably and HIV-1 protease inhibitor. Exemplary HIV-1 protease 30 inhibitors include, for example, saquinavir, ritonavir, indinavir, nelfinavir, amprenavir, and HIV-1 protease

inhibitors that are undergoing clinical trials, e.g., tipranavir (PNU-140690).

Suitable plasmepsin inhibitors include, for example, inhibitors of plasmepsin I or II, including inhibitors of 5 plasmepsin I or II that have antimalarial activity.

Suitable inhibitors of cathepsin D include, for example, cathepsin D inhibitors that inhibit cathepsin D in primary breast cancer tissues, including cathepsin D inhibitors that inhibit cathepsin D in primary breast 10 cancer tissues and would be expected to lower the risk of metastasis and/or shorter relapse-free survival in breast cancer patients. See, e.g., Gulnik et al., *J. Mol. Biol.*, 227, 265-270 (1992).

Suitable reverse transcriptase inhibitors include, 15 for example, retroviral reverse transcriptase inhibitors, e.g., AZT, 3TC, ddI, ddC, D4T, and the like.

Suitable protein inhibitors include, for example, compounds that inhibit a conformational change in a protein, and the like. Suitable oligomerization 20 inhibitors include, for example, T-20 peptide inhibitor of HIV-1 fusion and other compounds that inhibit oligomers from oligomerizing on a cell surface or within a cell membrane.

In accordance with the present invention, fitness in 25 the presence of an inhibitor can be determined for a biological entity that produces or includes a biological target of the inhibitor. The biological entity is preferably a replicating biological entity, for example, a virus, a parasite, or a cell, preferably a disease-causing 30 cell. Disease-causing replicating biological entities include, for example, tumor cells, cancer cells, and

infectious organisms (e.g., fungi, protozoa, bacteria, and the like) and prions.

Cancer cells include, for example, cells associated with breast cancer, colon cancer, lung cancer, and the like. Fitness can be determined for a rapidly growing tumor cell.

Fungi include, for example, *candida albicans*, and the like. Protozoa include, for example, trypanosome species, schistosomal species, malarial protozoa, e.g., *Plasmodium* species. *Plasmodium* species include, for example, *Plasmodium Falciparum*, *Plasmodium ovale*, *Plasmodium vivax*, *Plasmodium malariae*, and the like. Bacteria include, for example, *Helicobacter pylori*, *Escherichia coli*, *Salmonella*, *Streptococcus pyogenes*, *Staphylococcus aureas*, *Bacillus anthrax*, *Mycobacterium tuberculosis*, *Hemophilus influenza*, and the like. Viruses include, for example, retroviruses (e.g., HIV-1 and HIV-2), herpes viruses, cytomegaloviruses, influenza viruses, epstein-barr virus (EBV), Kaposi's sarcoma herpes virus (KSHV), varicella-zoster virus (VZV), human papillomavirus (HPV), echovirus, picornaviruses, rhinoviruses, poliovirus, coxsackie virus, measles, mumps, human T-cell leukemia virus (HTLV-1), rubella, rotaviruses, yellow fever virus, ebola virus, and other pathogenic viruses, and the like.

Replicating biological entities also include multicellular organisms, for example, infectious microorganisms, e.g., helminths. Helminths include, for example, hookworms (e.g., *ancylostoma duodenale*) *strongyloides stercoralis*, *fasciola hepatica*, *trichuris trichiura*, *trichinella spiralis*, *taenia solium*, *taenia saginata*, and the like.

It is believed that drug resistance is the evolutionary result of fitness-based selection of mutant cells/microorganisms in the presence of a drug (or any compound that has biological activity). In accordance with the present invention, the emergence (or non-emergence) of drug resistance in a disease caused by a disease-causing replicating biological entity can be predicted by determining the fitness of a biochemical target of a mutant in the presence of the drug. Thus, the emergence (or non-emergence) of drug resistance can be predicted on the basis of biochemical fitness. While resistance profiles may, in some instances, reflect fitness, it cannot be assumed that the emergence of drug resistance for a particular mutant can be directly predicted on the basis of its resistance profile alone.

The present invention thus provides an assay that can be used to predict the biological fitness of a replicating biological entity in the presence of a particular inhibitor. In a preferred embodiment, an assay is provided for determining the biochemical fitness of a biochemical target of a mutant replicating biological entity relative to its predecessor. In accordance with the assay of the present invention, a predecessor to the mutant is obtained, the biochemical vitality of the biochemical target of the predecessor in the presence of a compound capable of inhibiting the biochemical target of the predecessor is determined, the biochemical vitality of the biochemical target of the mutant in the presence of the compound is determined, and the biochemical vitality of the biochemical target of the

mutant relative to the biochemical vitality of the biochemical target of the predecessor are compared.

The assay can be used with a wide variety of infectious microorganisms, as described above, including, 5 for example, a virus, a fungus, a protozoa, or bacterium, a retrovirus, including HIV-1 or HIV-2, and cancer cells. When the infectious microorganism is a protozoa, it is preferably a malarial parasite, which is more preferably a plasmodium species.

10 In another embodiment, the predecessor is a cancer cell, which is preferably a rapidly growing tumor cell, for example, a rapidly growing cancer cell found in breast cancer, colon cancer, lung cancer, a tumor cell of a lymphoid origin, a tumor-derived cell with a high 15 metastatic potential, or the like.

The assay of the present invention can be applied to any suitable biochemical target, preferably a biochemical target whose biochemical vitality can be determined using measurable properties that can be obtained by assay.

20 Desirably, the biochemical target is one that plays an important role in the replication and growth of the entity. By way of example, the biochemical target of the predecessor (and the mutant) can be an enzyme and the compound can be an inhibitor of the enzyme of the 25 predecessor.

The enzyme can be a viral enzyme. Illustrative of viral enzymes are a viral protease enzyme, a viral reverse transcriptase, a viral integrase, a viral polymerase, a viral protein with enzymatic activity, or a 30 retroviral enzyme, including an HIV-1 or an HIV-2 enzyme. Viral protease enzymes, include a retroviral protease,

such as an HIV-1 protease or an HIV-2 protease. Viral integrase enzymes include, for example, HIV-1 integrase, HIV-2 integrase, and the like. Viral polymerase can be a retroviral polymerase, including an HIV-1 polymerase or 5 an HIV-2 polymerase. A viral protein with enzymatic activity can be a retroviral protein, such as an HIV-1 protein or an HIV-2 protein.

The enzyme also can be a protozoal enzyme, including a protozoal protease enzyme. The protozoal protease can 10 be a malarial protease. The malarial protease can be a plasmepsin, including plasmepsin I or plasmepsin II. The malarial enzyme can also be a plasmodial enzyme or a protein with enzymatic activity.

In yet another embodiment, the biochemical target of 15 the predecessor is an oligomer and the compound inhibits the oligomerization of the oligomer of the predecessor. In yet another embodiment, the biochemical target of the predecessor is a protein and the compound inhibits a conformational change in the protein of the predecessor.

20 The biochemical vitality determination can also take into account other factors, preferably measurable factors, that effect the ability of a biochemical target to perform its biochemical function in the presence of the inhibitor. When the biochemical target is an enzyme 25 and the compound is an enzyme inhibitor, the biochemical vitality of the enzyme of the mutant replicating biological entity preferably corresponds to  $K_{inh-mut}$ ,  $k_{cat-mut}$ ,  $K_m-mut$ , and the biochemical vitality of the enzyme of the predecessor preferably corresponds to  $K_{inh-pred}$ ,  $k_{cat-pred}$ , and 30  $K_m-pred$ .  $K_{inh}$  is an inhibition constant of the compound,  $k_{cat}$  is the biochemical catalytic rate, and  $K_m$  is the

Michaelis constant. More preferably, the vitality of the enzyme corresponds to  $K_{inh}$ ,  $k_{cat}$  and  $K_M$ , and the biochemical vitality of the enzyme of the mutant replicating biological entity is defined by the relationship  $K_{inh-mut}$  5  $\frac{k_{cat-mut}}{K_{M-mut}}$  (i.e.,  $(K_{inh-mut}) \times (K_{cat-mut}/K_{M-mut})$ ) and the biochemical vitality of the enzyme of the predecessor is defined by the relationship  $K_{inh-pred}$   $\frac{k_{cat-pred}}{K_{M-pred}}$ . The variables  $K_{inh-mut}$ ,  $K_{inh-pred}$ ,  $k_{cat-mut}$ ,  $k_{cat-pred}$ ,  $K_{M-mut}$ , and  $K_{M-pred}$  can be obtained by any suitable means, and are preferably 10 obtained by measurement (e.g., from an assay). When vitality is determined on the basis of these relationships, biochemical fitness in the presence of a given inhibitor/drug preferably is defined by the equation:

15 
$$\frac{K_{inh-mut} (k_{cat-mut}/K_{M-mut})}{K_{inh-pred} (k_{cat-pred}/K_{M-pred})}, \text{ or}$$

$$\log \left[ \frac{K_{inh-mut} (k_{cat-mut}/K_{M-mut})}{K_{inh-pred} (k_{cat-pred}/K_{M-pred})} \right]$$

$K_{inh}$  can be determined by any suitable means, but typically is determined on the basis of  $K_i$  or  $K_d$ .

20 The present invention also provides a method of administering a therapeutic compound, which method increases the chances of successful long-term therapy. In a preferred embodiment, the present invention provides a method of administering a therapeutic compound that 25 inhibits a biochemical target of a replicating disease-causing replicating biological entity (disease causing predecessor), including identifying at least one mutant capable of evolving from the disease-causing predecessor.

A first biochemical vitality of the biochemical target of the disease-causing predecessor in the presence of a first compound capable of inhibiting the biochemical target of the disease-causing predecessor, and a first 5 biochemical vitality of the biochemical target of the mutant in the presence of the first compound, are determined.

Additional biochemical vitalities of the biochemical target of the disease-causing replicating biological 10 entity in the presence of additional compounds capable of inhibiting the biochemical target of the disease-causing cell, and additional biochemical vitalities of the biochemical target of the mutant in the presence of the additional compounds, are also determined.

15       Fitnesses in the presence of different inhibitors/drugs can be compared and a therapeutic compound administered on the basis of the comparison. A first biochemical fitness of the biochemical target of the mutant relative to the disease-causing predecessor is 20 determined by comparing the first biochemical vitality of the biochemical target of the mutant with the first biochemical vitality of the biochemical target of the disease-causing predecessor, and a second biochemical fitness of the biochemical target of the mutant relative 25 to the disease-causing replicating biological entity is determined by comparing the second biochemical vitality of the biochemical target of the mutant with the second biochemical vitality of the biochemical target of the disease-causing replicating biological entity.

30       Additional biochemical fitness determinations can be made in the presence of additional compounds. The biochemical

fitness values for one or more mutants in the presence of each compound are compared. A therapeutic compound is then administered from among the first and the additional compound(s), which therapeutic compound produces the

5 lowest biochemical fitness values.

In accordance with the method of the present invention, the replicating disease-causing replicating biological entity is less likely to develop resistance in the presence of the therapeutic compound. The

10 therapeutic compound can be administered from among any particular set of compounds, which can have the same biochemical target or different biochemical targets with respect to each other. The method of administering a compound in accordance with the present invention is,

15 therefore, not limited to comparing fitness in the presence of compounds that act on the same biochemical target.

In one embodiment, the disease-causing replicating biological entity is an infectious microorganism, for

20 example, a virus, a fungus, a protozoa, or a bacterium, more preferably a virus or a protozoa. When the infectious microorganism is a virus, it is preferably a retrovirus, which is more preferably HIV-1 or HIV-2, and most preferably HIV-1. When the infectious microorganism

25 is a protozoa, it is preferably a malarial parasite, which is more preferably a plasmodium species.

In another embodiment, the disease-causing replicating biological entity is a cancer cell, which is preferably a rapidly growing tumor cell, for example, a

30 rapidly growing cancer cell found in breast cancer, colon cancer, lung cancer, or the like.

The method of administering a compound in accordance with the present invention can be applied to any suitable biochemical target, preferably a biochemical target whose biochemical vitality can be determined using measurable properties that can be obtained by assay. In one embodiment, the biochemical target of the predecessor (and the mutant) is an enzyme and the compound inhibits an enzyme of the predecessor. The enzyme can be any enzyme whose biochemical vitality can be measured including, for example, an enzyme described herein in connection with the fitness assay of the present invention.

In another embodiment, the biochemical target of the disease-causing replicating biological entity is an oligomer and the compound inhibits the oligomerization of the oligomer of the predecessor. In yet another embodiment, the biochemical target of the disease-causing replicating biological entity is a protein and the compound inhibits a conformational change in the protein of the predecessor.

The biochemical vitality can be determined in any suitable manner. For example, vitality can be determined as described herein, e.g., as described in connection with the assay of the present invention.

When an infectious microorganism is tested in accordance with the assay of the present invention, the predecessor can be a wild-type species, or the predecessor can itself be a mutant species. In a particularly preferred embodiment, the predecessor is a retrovirus, which is more preferably a wild-type HIV-1 or HIV-2 strain, most preferably HIV-1. When the

predecessor is a wild-type HIV strain, the mutant replicating biological entity preferably has at least one mutation in the biochemical target thereof. When the predecessor has at least one mutation in the biochemical 5 target thereof, the mutant preferably has at least two mutations in the biochemical target thereof.

Similarly, when the method of administering a therapeutic compound in accordance with the present invention is used in connection with an infectious 10 microorganism, the disease-causing replicating biological entity can be a wild-type species, or the disease-causing entity can itself be a mutant species. In a particularly preferred embodiment, the disease-causing replicating biological entity is a retrovirus, which is more 15 preferably a wild-type HIV-1 or HIV-2 strain, most preferably HIV-1. When the disease-causing replicating biological entity is a wild-type HIV strain, the mutant preferably has at least one mutation in the biochemical target thereof. When the disease-causing replicating 20 biological entity has at least one mutation in the biochemical target thereof, the mutant preferably has at least two mutations in the biochemical target thereof.

When the predecessor or the disease-causing replicating biological entity in the assay of the present 25 invention, or in the method of administering a compound in accordance with the present invention, is a wild-type HIV strain, the biochemical target of the mutant preferably has at least one active site mutation. When the predecessor in the assay of the present invention has 30 at least one mutation, and the mutant replicating biological entity has at least two mutations, the

biochemical target of the predecessor or of the mutant preferably has at least one active site mutation. When the disease-causing replicating biological entity in the method of the present invention has at least one mutation 5 in the biochemical target thereof, and the mutant has at least two mutations in the biochemical target thereof, the biochemical target of the disease-causing entity or of the mutant preferably has at least one active site mutation.

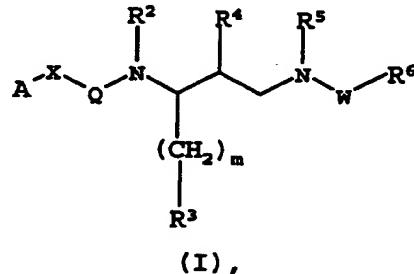
10 The present invention further provides a continuous fluorogenic assay for measuring the anti-HIV protease activity of a protease inhibitor, which method comprises adding a solution of HIV protease to a substrate stock solution, in which the substrate has the formula Ala-Arg- 15 Val-Tyr-Phe(NO<sub>2</sub>)-Glu-Ala-Nle-NH<sub>2</sub>, to provide a substrate reaction solution. The fluorescence of the substrate reaction solution is then measured at specified time intervals. The solution of HIV protease is then added to a solution of the protease inhibitor and the substrate 20 stock solution, to provide an inhibitor-substrate reaction solution. The fluorescence of the inhibitor-substrate reaction solution is then measured at specified time intervals. The initial velocity of the inhibitor-substrate reaction solution is then calculated by 25 applying the equation:

$$V = V_0 / 2E_t \left( \{ [K_i(1+S/K_m) + I_t - E_t]^2 + 4K_i(1+S/K_m)E_t \}^{1/2} - [K_i((1+S/K_m) + I_t - E_t)] \right)$$
, wherein V is the initial velocity of the inhibitor reaction solution,  $V_0$  is the initial velocity of the substrate reaction solution,  $K_m$  is the Michaelis-Menten 30 constant, S is the substrate concentration,  $E_t$  is the

protease concentration, and  $I_t$  is the inhibitor concentration.

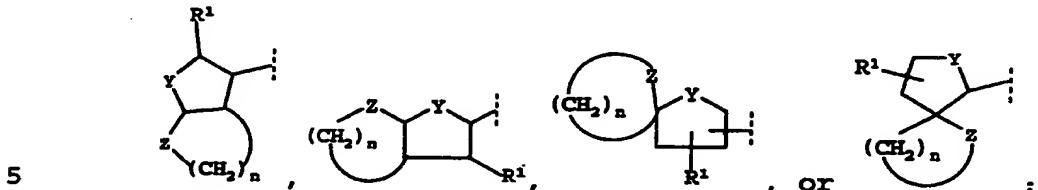
The assay method described herein is highly sensitive and particularly useful for the prediction of 5 the antiviral inhibitory activity of a compound against mutant HIV, more particularly multiple mutant HIV, specifically multidrug-resistant human immunodeficiency viruses. The continuous flourogenic assay of the present invention is distinctly advantageous in that it is more 10 sensitive than standard assays in determining the activity of protease inhibitors against multidrug-resistant HIV. The continuous flourogenic assay of the present invention is disclosed in more detail in the examples that follow. The inhibitory data obtained in 15 accordance with this continuous fluorogenic assay can be used to determine vitality and fitness for HIV-1 protease in the presence of a protease inhibitor, in accordance with the present invention.

The present invention also provides a method of 20 preventing the emergence of drug resistance in an HIV-infected mammal that includes the administration of a drug resistance-inhibiting effective amount of a compound represented by the formula:



or a pharmaceutically acceptable salt, a prodrug, or an ester thereof, or a pharmaceutical composition thereof, wherein:

A is a group of the formula:



R<sup>1</sup> is H or an alkyl, an alkenyl, an alkynyl, a cycloalkyl, a cycloalkylalkyl, an aryl, an aralkyl, a heterocycloalkyl, a heterocycloalkylalkyl, a heteroaryl, or a heteroaralkyl radical, in which at least one 10 hydrogen atom is optionally substituted with a substituent independently selected from the group consisting of OR<sup>7</sup>, SR<sup>7</sup>, CN, NO<sub>2</sub>, N<sub>3</sub>, and a halogen, wherein R<sup>7</sup> is H, an alkyl, an alkenyl, or an alkynyl;

Y and Z are the same or different and are 15 independently selected from the group consisting of CH<sub>2</sub>, O, S, SO, SO<sub>2</sub>, NR<sup>8</sup>, R<sup>8</sup>C(O)N, R<sup>8</sup>C(S)N, R<sup>8</sup>OC(O)N, R<sup>8</sup>OC(S)N, R<sup>8</sup>SC(O)N, R<sup>8</sup>R<sup>9</sup>NC(O)N, and R<sup>8</sup>R<sup>9</sup>NC(S)N, wherein R<sup>8</sup> and R<sup>9</sup> are independently selected from the group consisting of H, an alkyl, an alkenyl, and an alkynyl;

20 n is an integer from 1 to 5;

X is a covalent bond, CHR<sup>10</sup>, CHR<sup>10</sup>CH<sub>2</sub>, CH<sub>2</sub>CHR<sup>10</sup>, O, NR<sup>10</sup>, or S, wherein R<sup>10</sup> is H, an alkyl, an alkenyl, or an alkynyl;

25 Q is C(O), C(S), or SO<sub>2</sub>;

R<sup>2</sup> is H, an alkyl, an alkenyl, or an alkynyl;

m is an integer from 0 to 6;

R<sup>3</sup> is a cycloalkyl, a heterocycloalkyl, an aryl, or a heteroaryl in which at least one hydrogen atom is

optionally substituted with a substituent independently selected from the group consisting of H, alkyl,  $(CH_2)_pR^{11}$ ,  $OR^{12}$ ,  $SR^{12}$ , CN,  $NO_2$ ,  $NR^{12}R^{13}$ ,  $C(O)R^{12}$ ,  $C(S)R^{12}$ ,  $CO_2R^{12}$ ,  $C(O)SR^{12}$ ,  $C(O)NR^{12}R^{13}$ ,  $C(S)NR^{12}R^{13}$ ,  $NR^{12}C(O)R^{13}$ ,  $NR^{12}C(S)R^{13}$ ,

5  $NR^{12}CO_2R^{13}$ ,  $NR^{12}C(O)SR^{13}$ , and a halogen, wherein:

$p$  is an integer from 0 to 5;

$R^{11}$  is a cycloalkyl, a heterocycloalkyl, an aryl, or a heteroaryl in which at least one hydrogen atom is optionally substituted with a substituent

10 10 independently selected from the group consisting of a halogen, OH,  $OCH_3$ ,  $NH_2$ ,  $NO_2$ , SH, and CN; and

$R^{12}$  and  $R^{13}$  are independently selected from the group consisting of H, an alkyl, an alkenyl, and an alkynyl;

15 15  $R^4$  is OH, =O (keto), or  $NH_2$ , wherein, when  $R^4$  is OH, it is optionally in the form of a pharmaceutically acceptable ester or prodrug, and when  $R^4$  is  $NH_2$ , it is optionally an amide, a hydroxylamino, a carbamate, a urea, an alkylamino, a dialkylamino, a protic salt, or a

20 20 tetraalkylammonium salt;

$R^5$  is H, a  $C_1$ - $C_6$  alkyl radical, a  $C_2$ - $C_6$  alkenyl radical, or  $(CH_2)_qR^{14}$ , wherein  $q$  is an integer from 0 to 5, and  $R^{14}$  is a cycloalkyl, a heterocycloalkyl, an aryl, or a heteroaryl radical in which at least one hydrogen atom is

25 25 optionally substituted with a substituent independently selected from the group consisting of a halogen, OH,  $OCH_3$ ,  $NH_2$ ,  $NO_2$ , SH, and CN;

$W$  is  $C(O)$ ,  $C(S)$ ,  $S(O)$ , or  $SO_2$ ; and

$R^6$  is a cycloalkyl, heterocycloalkyl, aryl, or

30 30 heteroaryl radical in which at least one hydrogen atom is optionally substituted with a substituent independently

selected from the group consisting of a halogen,  $OR^{15}$ ,  $SR^{15}$ ,  $S(O)R^{15}$ ,  $SO_2R^{15}$ ,  $SO_2NR^{15}R^{16}$ ,  $SO_2N(OH)R^{15}$ ,  $CN$ ,  $CR^{15}=NR^{16}$ ,  $CR^{15}=N(OR^{16})$ ,  $N_3$ ,  $NO_2$ ,  $NR^{15}R^{16}$ ,  $N(OH)R^{15}$ ,  $C(O)R^{15}$ ,  $C(S)R^{15}$ ,  $CO_2R^{15}$ ,  $C(O)SR^{15}$ ,  $C(O)NR^{15}R^{16}$ ,  $C(S)NR^{15}R^{16}$ ,  $C(O)N(OH)R^{15}$ ,

5  $C(S)N(OH)R^{15}$ ,  $NR^{15}C(O)R^{16}$ ,  $NR^{15}C(S)R^{16}$ ,  $N(OH)C(O)R^{15}$ ,  $N(OH)C(S)R^{15}$ ,  $NR^{15}CO_2R^{16}$ ,  $N(OH)CO_2R^{15}$ ,  $NR^{15}C(O)SR^{16}$ ,  $NR^{15}C(O)NR^{16}R^{17}$ ,  $NR^{15}C(S)NR^{16}R^{17}$ ,  $N(OH)C(O)NR^{15}R^{16}$ ,  $N(OH)C(S)NR^{15}R^{16}$ ,  $NR^{15}C(O)N(OH)R^{16}$ ,  $NR^{15}C(S)N(OH)R^{16}$ ,  $NR^{15}SO_2R^{16}$ ,  $NHSO_2NR^{15}R^{16}$ ,  $NR^{15}SO_2NHR^{16}$ ,  $P(O)(OR^{15})(OR^{16})$ , an

10 alkyl, an alkoxy, an alkylthio, an alkylamino, a cycloalkyl, a cycloalkylalkyl, a heterocycloalkyl, a heterocycloalkylalkyl, an aryl, an aryloxy, an arylamino, an arylthio, an aralkyl, an aryloxyalkyl, an arylaminoalkyl, an aralkoxy, an (aryloxy)alkoxy, an

15 (arylamino)alkoxy, an (arylthio)alkoxy, an aralkylamino, an (aryloxy)alkylamino, an (arylamino)alkylamino, an (arylthio)alkylamino, an aralkylthio, an (aryloxy)alkylthio, an (arylthio)alkylthio, a heteroaryl, a heteroaryloxy, a

20 heteroarylaminio, a heteroarylthio, a heteroaralkyl, a heteroaralkoxy, a heteroaralkylamino, and a heteroaralkylthio,

wherein  $R^{15}$ ,  $R^{16}$ , and  $R^{17}$  are H, an unsubstituted alkyl, and an unsubstituted alkenyl,

25 wherein, when at least one hydrogen atom of  $R^6$  is optionally substituted with a substituent other than a halogen,  $OR^{15}$ ,  $SR^{15}$ ,  $S(O)R^{15}$ ,  $SO_2R^{15}$ ,  $SO_2NR^{15}R^{16}$ ,  $SO_2N(OH)R^{15}$ ,  $CN$ ,  $CR^{15}=NR^{16}$ ,  $CR^{15}=N(OR^{16})$ ,  $N_3$ ,  $NO_2$ ,  $NR^{15}R^{16}$ ,  $N(OH)R^{15}$ ,  $C(O)R^{15}$ ,  $C(S)R^{15}$ ,  $CO_2R^{15}$ ,  $C(O)SR^{15}$ ,  $C(O)NR^{15}R^{16}$ ,  $C(S)NR^{15}R^{16}$ ,

30  $C(O)N(OH)R^{15}$ ,  $C(S)N(OH)R^{15}$ ,  $NR^{15}C(O)R^{16}$ ,  $NR^{15}C(S)R^{16}$ ,  $N(OH)C(O)R^{15}$ ,  $N(OH)C(S)R^{15}$ ,  $NR^{15}CO_2R^{16}$ ,  $N(OH)CO_2R^{15}$ ,

NR<sup>15</sup>C(O)SR<sup>16</sup>, NR<sup>15</sup>C(O)NR<sup>16</sup>R<sup>17</sup>, NR<sup>15</sup>C(S)NR<sup>16</sup>R<sup>17</sup>, N(OH)C(O)NR<sup>15</sup>R<sup>16</sup>, N(OH)C(S)NR<sup>15</sup>R<sup>16</sup>, NR<sup>15</sup>C(O)N(OH)R<sup>16</sup>, NR<sup>15</sup>C(S)N(OH)R<sup>16</sup>, NR<sup>15</sup>SO<sub>2</sub>R<sup>16</sup>, NHSO<sub>2</sub>NR<sup>15</sup>R<sup>16</sup>, NR<sup>15</sup>SO<sub>2</sub>NHR<sup>16</sup>, or P(O)(OR<sup>15</sup>)(OR<sup>16</sup>), then at least one hydrogen atom on said substituent is

5    optionally substituted with a halogen, OR<sup>15</sup>, SR<sup>15</sup>, S(O)R<sup>15</sup>, SO<sub>2</sub>R<sup>15</sup>, SO<sub>2</sub>NR<sup>15</sup>R<sup>16</sup>, SO<sub>2</sub>N(OH)R<sup>15</sup>, CN, CR<sup>15</sup>=NR<sup>16</sup>, CR<sup>15</sup>=N(OR<sup>16</sup>), N<sub>3</sub>, NO<sub>2</sub>, NR<sup>15</sup>R<sup>16</sup>, N(OH)R<sup>15</sup>, C(O)R<sup>15</sup>, C(S)R<sup>15</sup>, CO<sub>2</sub>R<sup>15</sup>, C(O)SR<sup>15</sup>, C(O)NR<sup>15</sup>R<sup>16</sup>, C(S)NR<sup>15</sup>R<sup>16</sup>, C(O)N(OH)R<sup>15</sup>, C(S)N(OH)R<sup>15</sup>, NR<sup>15</sup>C(O)R<sup>16</sup>, NR<sup>15</sup>C(S)R<sup>16</sup>, N(OH)C(O)R<sup>15</sup>, N(OH)C(S)R<sup>15</sup>,

10    NR<sup>15</sup>CO<sub>2</sub>R<sup>16</sup>, N(OH)CO<sub>2</sub>R<sup>15</sup>, NR<sup>15</sup>C(O)SR<sup>16</sup>, NR<sup>15</sup>C(O)NR<sup>16</sup>R<sup>17</sup>, NR<sup>15</sup>C(S)NR<sup>16</sup>R<sup>17</sup>, N(OH)C(O)NR<sup>15</sup>R<sup>16</sup>, N(OH)C(S)NR<sup>15</sup>R<sup>16</sup>, NR<sup>15</sup>C(O)N(OH)R<sup>16</sup>, NR<sup>15</sup>C(S)N(OH)R<sup>16</sup>, NR<sup>15</sup>SO<sub>2</sub>R<sup>16</sup>, NHSO<sub>2</sub>NR<sup>15</sup>R<sup>16</sup>, NR<sup>15</sup>SO<sub>2</sub>NHR<sup>16</sup>, or P(O)(OR<sup>15</sup>)(OR<sup>16</sup>).

Optionally, R<sup>5</sup> and R<sup>6</sup> are covalently bonded such that

15    R<sup>5</sup> and R<sup>6</sup>, together with the N-W bond of formula (I), comprise a 12 to 18 membered ring. The 12 to 18 membered ring can comprise at least one additional heteroatom in the ring skeleton other than the nitrogen of the N-W bond (e.g., N, O, or S) within the ring. In the practice of

20    the method of preventing the emergence of drug resistance in an HIV-infected mammal, it is preferable that a mutant virus that is capable of evolving from the infection has low fitness, relative to the infecting virus, in the presence of the compound or combination of compounds that

25    are administered.

As utilized herein, the term "alkyl" means a straight-chain or branched alkyl radical containing from about 1 to about 20 carbon atoms chain, preferably from about 1 to about 10 carbon atoms, more preferably from

30    about 1 to about 8 carbon atoms, still more preferably from about 1 to about 6 carbon atoms. Examples of such

substituents include methyl, ethyl, propyl, isopropyl, *n*-butyl, *sec*-butyl, isobutyl, *tert*-butyl, pentyl, isoamyl, hexyl, octyl, dodecanyl, and the like.

The term "alkenyl" means a straight-chain or  
5 branched-chain alkenyl radical having one or more double bonds and containing from about 2 to about 20 carbon atoms chain, preferably from about 2 to about 10 carbon atoms, more preferably from about 2 to about 8 carbon atoms, still more preferably from about 2 to about 6 carbon  
10 atoms. Examples of such substituents include vinyl, allyl, 1,4-butadienyl, isopropenyl, and the like.

The term "alkynyl" means a straight-chain or branched-chain alkynyl radical having one or more triple bonds and containing from about 2 to about 20 carbon atoms  
15 chain, preferably from about 2 to about 10 carbon atoms, more preferably from about 2 to about 8 carbon atoms, still more preferably from about 2 to about 6 carbon atoms. Examples of such radicals include ethynyl, propynyl (propargyl), butynyl, and the like.

20 The term "alkoxy" means an alkyl ether radical, wherein the term "alkyl" is defined as above. Examples of alkoxy radicals include methoxy, ethoxy, *n*-propoxy, isopropoxy, *n*-butoxy, isobutoxy, *sec*-butoxy, *tert*-butoxy, hexanoxy, and the like.

25 The term "alkylthio" means an alkyl thioether radical, wherein the term "alkyl" is defined as above. Examples of alkylthio radicals include methylthio ( $\text{SCH}_3$ ), ethylthio ( $\text{SCH}_2\text{CH}_3$ ), *n*-propylthio, isopropylthio, *n*-butylthio, isobutylthio, *sec*-butylthio, *tert*-butylthio, *n*-  
30 hexylthio, and the like.

The term "alkylamino" means an alkyl amine radical, wherein the term "alkyl" is defined as above. Examples of alkylamino radicals include methylamino ( $\text{NHCH}_3$ ), ethylamino ( $\text{NHCH}_2\text{CH}_3$ ), *n*-propylamino, isopropylamino, *n*-butylamino, isobutylamino, *sec*-butylamino, *tert*-butylamino, *n*-hexylamino, and the like.

The term "cycloalkyl" means a monocyclic or a polycyclic alkyl radical defined by one or more alkyl carbocyclic rings, which can be the same or different when 10 the cycloalkyl is a polycyclic radical having 3 to about 10 carbon atoms in the carbocyclic skeleton in each ring, preferably about 4 to about 7 carbon atoms, more preferably 5 to 6 carbons atoms. Examples of monocyclic cycloalkyl radicals include cyclopropyl, cyclobutyl, 15 cyclopentyl, cyclohexyl, cycloheptyl, cyclodecyl, and the like. Examples of polycyclic cycloalkyl radicals include decahydronaphthyl, bicyclo[5.4.0]undecyl, adamantyl, and the like.

The term "cycloalkylalkyl" means an alkyl radical as 20 defined herein, in which at least one hydrogen atom on the alkyl radical is replaced by a cycloalkyl radical as defined herein. Examples of cycloalkylalkyl radicals include cyclohexylmethyl, 3-cyclopentylbutyl, and the like.

25 The term "heterocycloalkyl" means a cycloalkyl radical as defined herein (including polycyclics), wherein at least one carbon which defines the carbocyclic skeleton is substituted with a heteroatom such as, for example, O, N, or S, optionally comprising one or more double bond 30 within the ring, provided the ring is not heteroaryl as defined herein. The heterocycloalkyl preferably has 3 to

about 10 atoms (members) in the carbocyclic skeleton of each ring, preferably about 4 to about 7 atoms, more preferably 5 to 6 atoms. Examples of heterocycloalkyl radicals include epoxy, aziridyl, oxetanyl, 5 tetrahydrofuryl, dihydrofuryl, piperadyl, piperidinyl, pyperazyl, piperazinyl, pyranyl, morpholinyl, and the like.

The term "heterocycloalkylalkyl" means an alkyl radical as defined herein, in which at least one hydrogen 10 atom on the alkyl radical is replaced by a heterocycloalkyl radical as defined herein. Examples of heterocycloalkylalkyl radicals include 2-morpholinomethyl, 3-(4-morpholino)-propyl, 4-(2-tetrahydrofuryl)-butyl, and the like.

15 The term "aryl" refers to an aromatic carbocyclic radical, as commonly understood in the art, and includes monocyclic and polycyclic aromatics such as, for example, phenyl and naphthyl radicals, optionally substituted with one or more substituents selected from the group 20 consisting of a halogen, an alkyl, alkoxy, amino, cyano, nitro, and the like.

The term "aryloxy" means aryl as defined herein, wherein a hydrogen atom is replaced by an oxygen. Examples of aryloxy radicals include phenoxy, naphthoxy, 25 4-fluorophenoxy, and the like.

The term "aryl amino" means aryl as defined herein, wherein a hydrogen atom is replaced by an amine. Examples of aryl amino radicals include phenylamino, naphthylamino, 3-nitrophenylamino, 4-aminophenylamino, and the like.

30 The term "arylthio" means aryl as defined herein, wherein a hydrogen atom is replaced by a sulfur atom.

Examples of arylthio radicals include phenylthio, naphthylthio, 3-nitrophenylthio, 4-thiophenylthio, and the like.

The term "aralkyl" means alkyl as defined herein, 5 wherein an alkyl hydrogen atom is replaced by an aryl as defined herein. Examples of aralkyl radicals include benzyl, phenethyl, 3-(2-naphthyl)-butyl, and the like.

The term "aryloxyalkyl" means alkyl as defined herein, wherein an alkyl hydrogen atom is replaced by an 10 aryloxy as defined herein. Examples of aryloxyalkyl radicals include phenoxyethyl, 4-(3-aminophenoxy)-1-butyl, and the like.

The term "arylarninoalkyl" means alkyl as defined herein, wherein an alkyl hydrogen atom is replaced by an 15 arylarnino as defined herein. Examples of arylarninoalkyl radicals include phenylarninoethyl, 4-(3-methoxyphenylarnino)-1-butyl, and the like.

The term "aralkoxy" means alkoxy as defined herein, wherein an alkyl hydrogen atom is replaced by an aryl as 20 defined herein. Examples of aralkoxy radicals include 2-phenylethoxy, 2-phenyl-1-propoxy, and the like.

The term "(aryloxy)alkoxy" means alkoxy as defined herein, wherein an alkyl hydrogen atom is replaced by an aryloxy as defined herein. Examples of (aryloxy)alkoxy 25 radicals include 2-phenoxyethoxy, 4-(3-aminophenoxy)-1-butoxy, and the like.

The term "(arylarnino)alkoxy" means alkoxy as defined herein, wherein an alkyl hydrogen atom is replaced by an arylarnino as defined herein. Examples of 30 (arylarnino)alkoxy radicals include 2-(phenylarnino)-ethoxy, 2-(2-naphthylarnino)-1-butoxy, and the like.

The term "(arylthio)alkoxy" means alkoxy as defined herein, wherein an alkyl hydrogen atom is replaced by an arylthio as defined herein. Examples of (arylthio)alkoxy radicals include 2-(phenylthio)-ethoxy, and the like.

5 The term "aralkylamino" means alkylamino as defined herein, wherein an alkyl hydrogen atom is replaced by an aryl as defined herein. Examples of aralkylamino radicals include 2-phenethylamino, 4-phenyl-n-butyramino, and the like.

10 The term "(aryloxy)alkylamino" means alkylamino as defined herein, wherein an alkyl hydrogen atom is replaced by an aryloxy as defined herein. Examples of (aryloxy)alkylamino radicals include 3-phenoxy-n-propylamino, 4-phenoxybutylamino, and the like.

15 The term "(arylarnino)alkylamino" means alkylamino as defined herein, wherein an alkyl hydrogen atom is replaced by an arylamino as defined herein. Examples of (arylarnino)alkylamino radicals include 3-(naphthylamino)-1-propylamino, 4-(phenylamino)-1-butyramino, and the like.

20 The term "(arylthio)alkylamino" means alkylamino as defined herein, wherein an alkyl hydrogen atom is replaced by an arylthio as defined herein. Examples of (arylthio)alkylamino radicals include 2-(phenylthio)-ethylamino, and the like.

25 The term "aralkylthio" means alkylthio as defined herein, wherein an alkyl hydrogen atom is replaced by an aryl as defined herein. Examples of aralkylthio radicals include 3-phenyl-2-propylthio, 2-(2-naphthyl)-ethylthio, and the like.

30 The term "(aryloxy)alkylthio" means alkylthio as defined herein, wherein an alkyl hydrogen atom is replaced

by an aryloxy as defined herein. Examples of (aryloxy)alkylthio radicals include 3-phenoxypropylthio, 4-(2-fluorophenoxy)-butylthio, and the like.

The term "(arylaminio)alkylthio" means alkylthio as defined herein, wherein an alkyl hydrogen atom is replaced by an arylamino as defined herein. Examples of (arylaminio)alkylthio radicals include 2-(phenylamino)-ethylthio, 3-(2-naphthylamino)-n-propylthio, and the like.

The term "(arylthio)alkylthio" means alkylthio as defined herein, wherein an alkyl hydrogen atom is replaced by an arylthio as defined herein. Examples of (arylthio)alkylthio radicals include 2-(naphthylthio)-ethylthio, 3-(phenylthio)-propylthio, and the like.

The term "heteroaryl" means a radical defined by an aromatic heterocyclic ring as commonly understood in the art, including monocyclic radicals such as, for example, imidazole, thiazole, pyrazole, pyrrole, furane, pyrazoline, thiophene, oxazole, isoxazol, pyridine, pyridone, pyrimidine, pyrazine, and triazine radicals, and also including polycyclics such as, for example, quinoline, isoquinoline, indole, and benzothiazole radicals, which heteroaryl radicals are optionally substituted with one or more substituents selected from the group consisting of a halogen, an alkyl, alkoxy, amino, cyano, nitro, and the like. It will be appreciated that the heterocycloalkyl and heteroaryl substituents can be coupled to the compounds of the present invention via a heteroatom, such as nitrogen (e.g., 1-imidazolyl).

The term "heteroaryloxy" means heteroaryl as defined herein, wherein a hydrogen atom on the heteroaryl ring is replaced by an oxygen. Heteroaryloxy radicals include,

for example, 4-pyridyloxy, 5-quinolyloxy, and the like.

The term "heteroaryl amino" means heteroaryl as defined herein, wherein a hydrogen atom on the heteroaryl ring is replaced by an nitrogen. Heteroaryl amino radicals 5 include, for example, 4-thiazolylamino, 2-pyridylamino, and the like.

The term "heteroarylthio" means heteroaryl as defined herein, wherein a hydrogen atom on the heteroaryl ring is replaced by a sulfur. Heteroarylthio radicals include, 10 for example, 3-pyridylthio, 3-quinolylthio, 4-imidazolylthio, and the like.

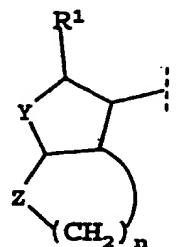
The term "heteroaralkyl" means alkyl as defined herein, wherein an alkyl hydrogen atom is replaced by a heteroaryl as defined herein. Examples of heteroaralkyl 15 radicals include 2-pyridylmethyl, 3-(4-thiazolyl)-propyl, and the like.

The term "heteroaralkoxy" means alkoxy as defined herein, wherein an alkyl hydrogen atom is replaced by a heteroaryl as defined herein. Examples of heteroaralkoxy 20 radicals include 2-pyridylmethoxy, 4-(1-imidazolyl)-butoxy, and the like.

The term "heteroaralkylamino" means alkylamino as defined herein, wherein an alkyl hydrogen atom is replaced by a heteroaryl as defined herein. Examples of 25 heteroaralkylamino radicals include 4-pyridylmethylamino, 3-(2-furanyl)-propylamino, and the like.

The term "heteroaralkylthio" means alkylthio as defined herein, wherein an alkyl hydrogen atom is replaced by a heteroaryl as defined herein. Examples of 30 heteroaralkylthio radicals include 3-pyridylmethythio, 3-(4-thiazolyl)-propylthio, and the like.

In the compound of Formula I, A is preferably a group of the formula:



$R^1$  is H or an alkyl, an alkenyl, a cycloalkyl, a cycloalkylalkyl, an aryl, an aralkyl, a heterocycloalkyl, a heterocycloalkylalkyl, a heteroaryl, or a heteroaralkyl radical, in which at least one hydrogen atom is optionally substituted with a substituent independently selected from the group consisting of  $OR^7$ ,  $SR^7$ ,  $CN$ ,  $NO_2$ ,  $N_3$ , and a halogen, wherein  $R^7$  is H, an unsubstituted alkyl, or an unsubstituted alkenyl; Y and Z are the same or different and are independently selected from the group consisting of  $CH_2$ , O, S,  $SO$ ,  $SO_2$ ,  $NR^8$ ,  $R^8C(O)N$ ,  $R^8C(S)N$ ,  $R^8OC(O)N$ ,  $R^8OC(S)N$ ,  $R^8SC(O)N$ ,  $R^8R^9NC(O)N$ , and  $R^8R^9NC(S)N$ , wherein  $R^8$  and  $R^9$  are independently selected from the group consisting of H, an unsubstituted alkyl, and an unsubstituted alkenyl; X is a covalent bond,  $CHR^{10}$ ,  $CHR^{10}CH_2$ ,  $CH_2CHR^{10}$ , O,  $NR^{10}$ , or S, wherein  $R^{10}$  is H, an unsubstituted alkyl, or an unsubstituted alkenyl radical;  $R^2$  is H, a  $C_1-C_6$  alkyl radical, or a  $C_2-C_6$  alkenyl radical;  $R^{12}$  and  $R^{13}$ , as defined with respect to  $R^3$ , are independently selected from the group consisting of H, an unsubstituted alkyl, and an unsubstituted alkenyl radical;  $R^4$  is OH,  $NH_2$ , or  $NHCH_3$ ; W is  $C(O)$ ,  $C(S)$ , or  $SO_2$ ; and  $R^6$  is a cycloalkyl, heterocycloalkyl, aryl, or heteroaryl radical in which at least one hydrogen atom is optionally

substituted with a substituent independently selected from the group consisting of a halogen,  $OR^{15}$ ,  $SR^{15}$ ,  $CN$ ,  $N_3$ ,  $NO_2$ ,  $NR^{15}R^{16}$ ,  $C(O)R^{15}$ ,  $C(S)R^{15}$ ,  $CO_2R^{15}$ ,  $C(O)SR^{15}$ ,  $C(O)NR^{15}R^{16}$ ,  $C(S)NR^{15}R^{16}$ ,  $NR^{15}C(O)R^{16}$ ,  $NR^{15}C(S)R^{16}$ ,  $NR^{15}CO_2R^{16}$ ,  $NR^{15}C(O)SR^{16}$ ,  $NR^{15}C(O)NR^{16}R^{17}$ , and  $NR^{15}C(S)NR^{16}R^{17}$ , an alkyl, an alkoxy, an alkylthio, an alkylamino, a cycloalkyl, a cycloalkylalkyl, a heterocycloalkyl, a heterocycloalkylalkyl, an aryl, an aryloxy, an arylamino, an arylthio, an aralkyl, an aryloxyalkyl, an arylaminoalkyl, an aralkoxy, an (aryloxy)alkoxy, an (arylmino)alkoxy, an (arylthio)alkoxy, an aralkylamino, an (aryloxy)alkylamino, an (arylmino)alkylamino, an (arylthio)alkylamino, an aralkylthio, an (aryloxy)alkylthio, an (arylmino)alkylthio, an (arylthio)alkylthio, a heteroaryl, a heteroaryloxy, a heteroarylmino, a heteroarylthio, a heteroaralkyl, a heteroaralkoxy, a heteroaralkylamino, and a heteroaralkylthio, wherein  $R^{15}$ ,  $R^{16}$ , and  $R^{17}$  are H, an unsubstituted alkyl, and an unsubstituted alkenyl, such that when at least one hydrogen atom of  $R^6$  is optionally substituted with a substituent other than a halogen,  $OR^{15}$ ,  $SR^{15}$ ,  $CN$ ,  $N_3$ ,  $NO_2$ ,  $NR^{15}R^{16}$ ,  $C(O)R^{15}$ ,  $C(S)R^{15}$ ,  $CO_2R^{15}$ ,  $C(O)SR^{15}$ ,  $C(O)NR^{15}R^{16}$ ,  $C(S)NR^{15}R^{16}$ ,  $NR^{15}C(O)R^{16}$ ,  $NR^{15}C(S)R^{16}$ ,  $NR^{15}CO_2R^{16}$ ,  $NR^{15}C(O)SR^{16}$ ,  $NR^{15}C(O)NR^{16}R^{17}$ , or  $NR^{15}C(S)NR^{16}R^{17}$ , at least one hydrogen atom on said substituent attached to  $R^6$  is optionally substituted with a halogen,  $OR^{15}$ ,  $SR^{15}$ ,  $CN$ ,  $N_3$ ,  $NO_2$ ,  $NR^{15}R^{16}$ ,  $C(O)R^{15}$ ,  $C(S)R^{15}$ ,  $CO_2R^{15}$ ,  $C(O)SR^{15}$ ,  $C(O)NR^{15}R^{16}$ ,  $C(S)NR^{15}R^{16}$ ,  $NR^{15}C(O)R^{15}$ ,  $NR^{15}C(S)R^{16}$ ,  $NR^{15}CO_2R^{16}$ ,  $NR^{15}C(O)SR^{16}$ ,  $NR^{15}C(O)NR^{16}R^{17}$ , or  $NR^{15}C(S)NR^{16}R^{17}$ .

It is further preferred that when  $R^1$  is an alkyl or an alkenyl radical (i.e., an alkyl or an alkenyl

substituent), then it is a C<sub>1</sub>-C<sub>6</sub> alkyl or, in the case when R<sup>1</sup> is an alkenyl, it is a C<sub>2</sub>-C<sub>6</sub> alkenyl. When R<sup>1</sup> is a monocyclic substituent such as, for example, a cycloalkyl, a heterocycloalkyl, an aryl, or a heteroaryl,

5 it preferably comprises 4-7 members in the ring that defines the monocyclic skeleton. When R<sup>7</sup>, R<sup>8</sup> or R<sup>9</sup> is an unsubstituted alkyl, it is preferably a C<sub>1</sub>-C<sub>6</sub> unsubstituted alkyl; and when R<sup>7</sup>, R<sup>8</sup> or R<sup>9</sup> is an unsubstituted alkenyl, it is preferably a C<sub>2</sub>-C<sub>6</sub>

10 unsubstituted alkenyl. The ring defined by R<sup>3</sup> preferably comprises 4-7 members or, in the case of polycyclics, each ring comprises 4-7 members. When R<sup>3</sup> is (CH<sub>2</sub>)<sub>p</sub>R<sup>11</sup>, the ring defined by R<sup>11</sup> preferably comprises 4-7 members, or, in the case of polycyclics, each ring comprises 4-7

15 members. When either of R<sup>12</sup> or R<sup>13</sup> is an unsubstituted alkyl, it is preferably a C<sub>1</sub>-C<sub>6</sub> unsubstituted alkyl, and when either of R<sup>12</sup> or R<sup>13</sup> is an unsubstituted alkenyl, it is a C<sub>2</sub>-C<sub>6</sub> unsubstituted alkyl. When R<sup>14</sup> is a cycloalkyl, a heterocycloalkyl, an aryl, or a heteroaryl, the ring defined by R<sup>14</sup> preferably comprises 4-7 members, or, in the case of polycyclics, each ring comprises 4-7 members.

20 When R<sup>6</sup> is a cycloalkyl, a heterocycloalkyl, aryl, or a heteroaryl, the ring defined by R<sup>6</sup> preferably comprises 4-7 members, or, in the case of polycyclics, each ring

25 comprises 4-7 members, and when R<sup>6</sup> is substituted with a substituent that is an alkyl, an alkylthio, or an alkylamino, it is preferred that the substituent comprises from one to six carbon atoms, and when R<sup>6</sup> is substituted with a substituent that is a cycloalkyl, a

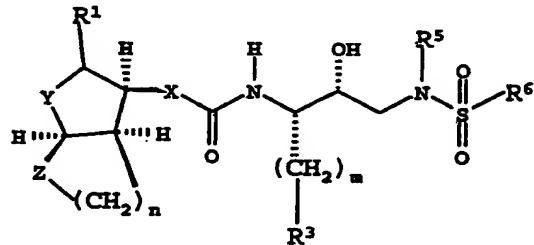
30 heterocycloalkyl, an aryl, or a heteroaryl, the ring defined by the substituent preferably comprises 4-7

members or, in the case of polycyclics, each ring comprises 4-7 members.

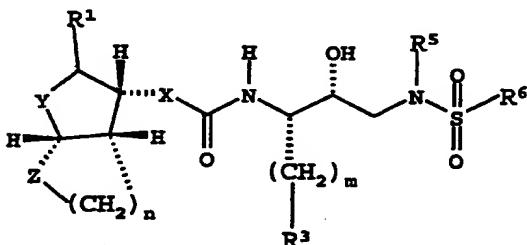
In a preferred embodiment, the method of preventing the emergence of resistance in accordance with the

5 present invention includes administering a compound of Formula (I), wherein Q is C(O), R<sup>2</sup> is H, and W is C(O) or SO<sub>2</sub>. In a further preferred embodiment, Q is C(O), R<sup>2</sup> is H, R<sup>4</sup> is OH, W is SO<sub>2</sub>, and the stereochemical orientation of the asymmetric centers is represented by formula (IA)

10 or (IB) below:



(IA) or

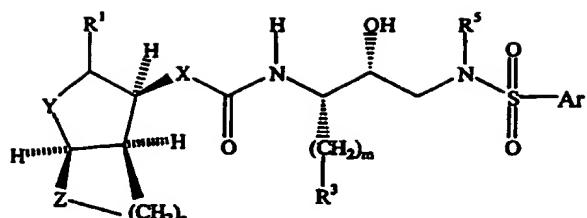


15

(IB).

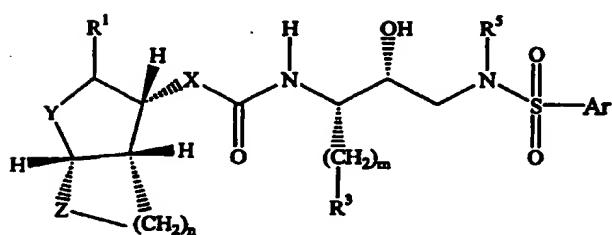
It is further preferred that R<sup>6</sup> is a monocyclic substituent, preferably an aromatic ring, which is preferably a substituted benzene ring, as illustrated by 20 the formula:

49



(IC)

or

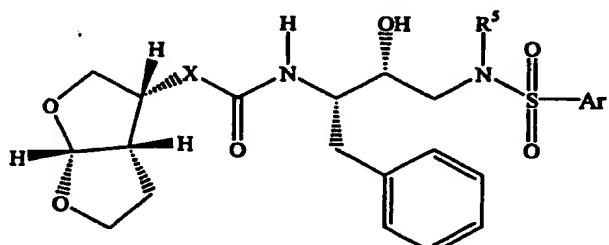


5

(ID),

wherein Ar is a phenyl which is optionally substituted with a substituent selected from the group consisting of methyl, amino, hydroxy, methoxy, methylthio, hydroxymethyl, aminomethyl, and methoxymethyl.

10 In a preferred series, Y and Z are oxygen atoms, n is 2, the resulting bis-tetrahydrofuranyl ring system has the stereochemical orientations illustrated in Formulae (IC) and (ID) above, m is 1, and R<sup>3</sup> is phenyl, in which case the compound is represented by the formula:

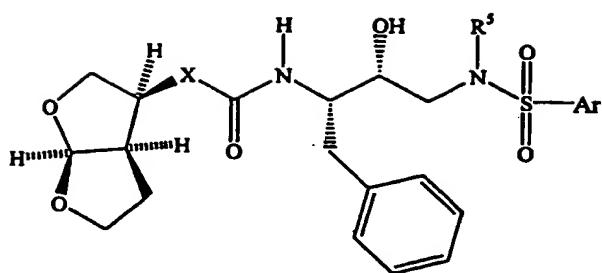


15

(IE)

or

50



wherein Ar is a phenyl which is optionally substituted with a substituent selected from the group consisting of

5 methyl, amino, hydroxy, methoxy, methylthio, hydroxymethyl, aminomethyl, and methoxymethyl. When the compound is a compound of Formula (IE) or (IF), wherein at least one hydrogen atom on Ar substituted with a substituent selected from the group consisting of methyl,

10 amino, hydroxy, methoxy, methylthio, hydroxymethyl, and methoxymethyl, it is further preferred that X is an oxygen. Still more preferably, X is an oxygen and R<sup>5</sup> is isobutyl. Suitable Ar substituents include phenyl groups that are substituted at the para position, the meta

15 position, and/or the ortho position. Examples of suitable Ar substituents are shown in Table 4, and in Figures 3 and 5A-5D.

A resistance-inhibiting effective amount is an amount sufficient to produce an *in vivo* drug concentration or

20 level in which the biochemical vitality of a mutant HIV is lower than the biochemical vitality of the HIV (predecessor) infecting the HIV-infected mammal. For example, a resistance-inhibiting effective amount is an amount sufficient to produce an *in vivo* drug concentration

25 or level where the value for biochemical fitness is less than one, when determined by the ratio of the biochemical

## 51

vitality of the mutant to the biochemical vitality of the predecessor. The compound can be administered to a wild-type HIV-infected mammal to prevent the emergence of first line resistance, or it can be administered to a mammal 5 infected with a mutant-HIV to prevent the emergence of drug resistance due to further mutations.

The compound is preferably administered in the form of a pharmaceutical composition. The pharmaceutical composition preferably includes a pharmaceutically 10 acceptable carrier and a resistance-inhibiting effective amount of at least one of the aforesaid compound, alone or in combination with another antiretroviral compound such as, for example, a wild-type HIV protease inhibitor, a mutant HIV retroviral protease inhibitor, or a reverse 15 transcriptase inhibitor. Generally, the pharmaceutical composition of the present invention comprises a resistance-inhibiting effective amount of at least one compound of Formula (I), as disclosed herein, and a pharmaceutically acceptable carrier.

20 In a preferred embodiment, a pharmaceutical composition is administered that comprises a resistance-inhibiting effective amount of at least one compound of Formula (IA) or Formula (IB), or a pharmaceutically acceptable salt, prodrug, or ester thereof, and a 25 pharmaceutically acceptable carrier. In a further preferred embodiment, the pharmaceutical composition comprises a resistance-inhibiting effective amount of at least one compound of Formula (IC) or Formula (ID), or a pharmaceutically acceptable salt, prodrug, or ester 30 thereof, and a pharmaceutically acceptable carrier. In a highly preferred embodiment, the pharmaceutical

composition comprises a resistance-inhibiting effective amount of at least one compound of Formula (IE), and pharmaceutically acceptable salts, prodrugs, and esters thereof, and a pharmaceutically acceptable carrier.

5       Pharmaceutically acceptable carriers are well-known to those of skill in the art. The choice of a carrier will be determined in part by the particular composition, as well as by the particular mode of administration. Accordingly, there are a wide variety of suitable

10      formulations for administration in accordance the present invention.

The pharmaceutical composition may be administered in a form suitable for oral use such as, for example, tablets, troches, lozenges, aqueous or oily suspensions or

15      solutions, dispersible powders or granules, emulsions, hard or soft capsules, syrups or elixirs. Compositions intended for oral use may be prepared according to any method known in the art form the manufacture of pharmaceutical compositions, and such compositions can

20      contain one or more agents such as, for example, sweetening agents, flavoring agents, coloring agents, and preserving agents in order to provide a pharmaceutically elegant and/or palatable preparation. Tablets can contain the active ingredient in admixture with non-toxic

25      pharmaceutically acceptable excipients which are suitable for manufacture of tablets. Such excipients can be, for example, inert diluents such as, for example, calcium carbonate, lactose, calcium phosphate or sodium phosphate; granulating and disintegrating agents such as, for

30      example, maize starch or alginic acid; binding agents such as, for example, starch, gelatine or acacia, and

lubricating agents such as, for example, stearic acid or talc. The tablets may be uncoated or they may be coated by known techniques to delay disintegration and absorption in the gastrointestinal tract and thereby provide a

5 sustained action over a longer period. For example, a time delay material such as glyceryl monostearate or glyceryl distearate alone or with a wax may be employed.

Formulations for oral use also can be presented as hard gelatin capsules wherein the active ingredient is

10 mixed with an inert solid diluent, for example calcium carbonate, calcium phosphate or kaolin, or as soft gelatin capsules wherein the active ingredient is mixed with water or an oil medium, for example arachis oil, peanut oil, liquid paraffin or olive oil.

15 Aqueous suspensions typically contain the active materials in admixture with excipients suitable for the manufacture of aqueous suspensions. Such excipients are suspending agents, for example, sodium carboxymethyl cellulose, methylcellulose, hydroxypropylmethylcellulose,

20 sodium alginate, polyvinylpyrrolidone, gum tragacanth and gam acacia; dispersing or wetting agents may be a natural-occurring phosphatide, for example, lecithin, or condensation products of an alkylene oxide with fatty acids, for example polyoxyethylene stearate, or

25 condensation products of ethylene oxide with long chain aliphatic alcohols, for example heptadecaethyleneoxycetanol, or condensation products of ethylene oxide with partial esters derived from fatty acids and a hexitol such as polyoxyethylene sorbitol

30 monooleate, or condensation products of ethylene oxide with partial esters derived from fatty acids and hexitol

anhydrides, for example polyoxyethylene sorbitan mono-oleate. The aqueous suspensions also can contain one or more preservatives, for example, ethyl or n-propyl p-hydroxy benzoate, one or more coloring agents, one or more 5 flavoring agents and one or more sweetening agents such as, for example, sucrose or saccharin.

Oily suspensions may be formulated by suspending the active ingredient in a vegetable oil, for example arachis oil, olive oil, sesame oil or coconut oil, or in a mineral 10 oil such as liquid paraffin. The oil suspensions may contain a thickening agent, for example beeswax, hard paraffin or cetyl alcohol. Sweetening agents, such as those set forth above, and flavoring agents may be added to provide a palatable oral preparation. These 15 compositions can be preserved by the addition of an antioxidant such as, for example, ascorbic acid.

Dispersible powders and granules suitable for preparation of an aqueous suspension by the addition of water provide the active ingredient in admixture with a 20 dispersing or wetting agent, suspending agent and one or more preservatives. Suitable dispersing or wetting agents and suspending agents are exemplified by those already mentioned above. Additional excipients, for example sweetening, flavoring and coloring agents, also may be 25 present.

The pharmaceutical composition also can be administered in the form of oil-in-water emulsions. The oily phase can be a vegetable oil, for example, olive oil or arachis oils, or a mineral oil, for example liquid 30 paraffin or mixtures of these. Suitable emulsifying agents may be naturally-occurring gums, for example gum

acacia or gum tragacanth, naturally-occurring phosphatides, for example soya bean lecithin, and esters or partial esters derived from fatty acids and hexitol anhydrides, for example sorbitan mono-oleate, and

5 condensation products of the said partial esters and ethylene oxide, for example polyoxyethylene sorbitan mono-oleate. The emulsions also can contain sweetening and flavoring agents.

The pharmaceutical composition also can be

10 administered in the form of syrups and elixirs, which are typically formulated with sweetening agents such as, for example, glycerol, sorbitol or sucrose. Such formulations also can contain a demulcent, a preservative and flavoring and coloring agents.

15 Further, the pharmaceutical composition can be administered in the form of a sterile injectable preparation, for example, as a sterile injectable aqueous or oleaginous suspension. Suitable suspensions for parenteral administration can be formulated according to

20 the known art using those suitable dispersing or wetting agents and suspending agents which have been mentioned above. Formulations suitable for parenteral administration include, for example, aqueous and non-aqueous, isotonic sterile injection solutions, which can

25 contain anti-oxidants, buffers, bacteriostates, and solutes that render the formulation isotonic with the blood of the intended recipient, and aqueous and non-aqueous sterile suspensions that can include suspending agents, solubilizers, thickening agents, stabilizers, and

30 preservatives. The sterile injectable preparation can be a solution or a suspension in a non-toxic parenterally-

acceptable diluent or solvent, for example, as a solution in water or 1,3-butanediol. Among the acceptable vehicles and solvents that can be employed, for example, are water, Ringer's solution and isotonic sodium chloride solution.

- 5 In addition, sterile, fixed oils are conventionally employed as a solvent or suspending medium. For this purpose any bland fixed oil can be employed including synthetic mono- or diglycerides. In addition, fatty acids such as, for example, oleic acid find use in the
- 10 preparation of injectables.

Further, the compound can be administered in the form of suppositories for rectal administration of the drug. These compositions can be prepared by mixing the drug with a suitable non-irritating excipient which is solid at ordinary temperatures but liquid at the rectal temperature and will therefore melt in the rectum to release the drug. Such materials include, for example, cocoa butter and polyethylene glycols. Formulations suitable for vaginal administration can be presented as pessaries, tampons, creams, gels, pastes, and foams.

Formulations suitable for topical administration may be presented as creams, gels, pastes, or foams, containing, in addition to the active ingredient, such carriers as are known in the art to be appropriate.

- 25 The composition can be made into an aerosol formulation to be administered via inhalation. Such aerosol formulations can be placed into pressurized acceptable propellants, such as dichlorodifluoromethane, propane, nitrogen, and the like. They also can be
- 30 formulated as pharmaceuticals for non-pressured preparations such as in a nebulizer or an atomizer.

The formulations can be presented in unit-dose or multi-dose sealed containers, such as ampules and vials, and can be stored in a freeze-dried (lyophilized) condition requiring only the addition of the sterile

5 liquid excipient, for example, water, for injections, immediately prior to use. Extemporaneous injection solutions and suspensions can be prepared from sterile powders, granules, and tablets of the kind previously described.

10 Any suitable dosage level can be employed in the pharmaceutical compositions of the present invention. The dose administered to an animal, particularly a human, in the context of the present invention should be sufficient to effect a prophylactic or therapeutic response in the

15 animal over a reasonable time frame. The amount of active ingredient that can be combined with the carrier materials to produce a single dosage form will vary depending upon the host treated and the particular mode of administration. The size of the dose also will be

20 determined by the existence, nature, and extent of any adverse side-effects that might accompany the administration of a particular composition. Suitable doses and dosage regimens for the prevention of drug resistance can be determined by comparisons to

25 antiretroviral chemotherapeutic agents that are known to inhibit the proliferation of a retrovirus in an infected individual. The preferred dosage is the amount that results in the inhibition of the emergence of mutant drug-resistant retroviruses, particularly the emergence of

30 multidrug-resistant retroviral HIV, without significant side effects. In proper doses and with suitable

administration of certain compounds, a wide range of antiretroviral chemotherapeutic compositions are possible.

A suitable dose includes a dose or dosage which would be insufficient to completely suppress the growth of a wild-

5 type or predecessor virus, but would be sufficient to inhibit or effectively suppress the growth of a mutant.

In accordance with the present invention, the compound or composition can be administered in combination with other antiretroviral compounds such as, for example,

10 ritonavir, amprenavir, saquinavir, indinavir, AZT, ddI, ddC, D4T, lamivudine, 3TC, and the like, as well as admixtures and combinations thereof, in a pharmaceutically acceptable carrier. The individual daily dosages for these combinations can range from about one-fifth of the

15 minimally recommended clinical dosages to the maximum recommended levels for the entities when they are given singly.

The present invention also provides a method of preventing the emergence of multidrug-resistant

20 retroviruses in an HIV-infected mammal, which method comprises administering to the mammal a multidrug resistance-inhibiting effective amount of a compound of the present invention, so as to inhibit the emergence of a multidrug-resistant retrovirus in the mammal. The dose

25 administered to an animal, particularly a human in the context of the present invention, should be sufficient to effect a therapeutic response in the animal over a reasonable time frame. The dose will be determined by the strength of the particular composition employed and the

30 condition of the animal, as well as the body weight of the animal to be treated. The size of the dose will also be

determined by the existence, nature, and extent of any adverse side-effects that might accompany the administration of a particular compound. Other factors which effect the specific dosage include, for example,

5 bioavailability, metabolic profile, and the pharmacodynamics associated with the particular compound to be administered in a particular patient. One skilled in the art will recognize that the specific dosage level for any particular patient will depend upon a variety of

10 factors including, for example, the activity of the specific compound employed, the age, body weight, general health, sex, diet, time of administration, route of administration, rate of excretion, drug combination, CD4 count, the potency of the active compound with respect to

15 the particular mutant retroviral strain to be inhibited, and the severity of the symptoms presented prior to or during the course of therapy. What constitutes a resistance-inhibiting effective amount can be determined, in part, by use of one or more of the assays described

20 herein, particularly the fitness assay of the present invention.

One skilled in the art will appreciate that suitable methods of administering compounds and pharmaceutical compositions are available, and, although more than one

25 route can be used to administer a particular composition, a particular route can provide a more immediate and/or more effective reaction than another route.

Numerous compounds have been identified that exhibit potent antiretroviral activity, in particular retroviral

30 protease activity, against wild-type HIV. However, among the fifteen currently FDA-approved antiretroviral agents

which are all known potent inhibitors of wild-type HIV, five of which are potent inhibitors of wild-type HIV protease, none of these compounds have the ability to prevent the emergence of drug-resistance mutations that 5 are associated with high level cross resistance. Thus, these inhibitors do not have the ability to suppress the sufficiently fit mutant retroviruses that can (and almost certainly will) emerge under the selection pressure of these inhibitors.

10 Surprisingly, it has been discovered that compound 32 (shown in Figure 3A), which is a potent wild-type HIV inhibitor, possesses remarkably potent and unprecedented broad-spectrum inhibitory activity against a panel of recombinant mutant HIV protease targets. These enzymes 15 represent the key or primary resistance mutations, most of which occur in the active site region. Based on this finding, the compound was tested against a panel of drug resistant mutant patient isolates of HIV and was found to possess broad spectrum antiviral activity against a wide 20 range of clinically isolated, multiply drug-resistant, human immunodeficiency viruses. Other compounds described herein showed similar activity. The mutant viruses were obtained from infected humans who had received several antiviral drugs. Although applicants do 25 not wish to abound by any one particular theory, it is believed that the combination of the bicyclic ligand (vii) with isostere (vi) gives the antiretroviral compounds of the present invention the unique ability to bind to the active site of the mutant proteases of 30 multiply drug-resistant human immunodeficiency viruses generally, which trait has heretofore not been reported

with respect to any known chemotherapeutic and/or experimental HIV protease inhibitor. A wild-type preliminary screen was utilized to determine the antiretroviral activity of analogs against wild-type HIV.

5 It is predicted that compounds of Formula (I), which have potent antiretroviral or protease-inhibitory activity against wild-type HIV, also will be potent inhibitors of drug-resistance, even multiple drug-resistance, in wild-type HIV, or even a mutant thereof.

10 The resistance-inhibiting compounds of the present invention can be synthesized by any suitable method known in the art. The preferred synthesis method is generally illustrated in Figure 4, which is an representation of the synthetic approach to preparing a preferred series of

15 compounds, wherein a compound of Formula (I) is synthesized in several steps starting from azidoepoxide (i), wherein R<sup>1</sup>-R<sup>17</sup>, m, n, p, Q, W, X, y, and z are defined as above. Referring to Figure 4, amine (ii) is nucleophilically added to azidoepoxide (i), providing aminoalcohol (iii). The

20 amine functional group of aminoalcohol (iii) is then reacted with intermediate (iv), wherein L represents a leaving group (e.g., halogen, N-oxysuccinimide), which can be displaced by the amine of aminoalcohol (iii), to provide azide (v). Reduction of azide (v), or, when R<sup>5</sup> is not hydrogen,

25 reductive amination with aldehyde R<sup>5</sup>CH=O, provides intermediate (vi), which is subsequently coupled with activated bicyclic ligand (vii), to provide compounds of Formula I. Of course, it will be appreciated by a person of ordinary skill in the art that there are combinations of

30 substituents, functional groups, R-groups, and the like, which are reactive under particular reaction conditions, and require the utilization of an appropriate protecting group

or groups, which are known in the art, to ensure that the desired synthetic transformation will take place without the occurrence of undesired side reactions. For example, possible substituents at R<sup>5</sup> (e.g., NH<sub>2</sub>) can be competitive 5 nucleophiles requiring the attachment of an appropriate protecting group thereon (e.g., benzyloxycarbonyl, tert-butoxycarbonyl) in order obtain proper selectivity in the ring opening of epoxide (i) with amine (ii).

Figures 1-3B illustrate the synthesis of a preferred 10 series of compounds for use in the method of preventing the emergence of resistance in accordance with the present invention. Figure 1, which is a synthetic scheme for the synthesis of a particular sulfonamide, illustrates the synthesis of a preferred isosteric core, particularly, the 15 sulfonamide isosteric core represented by aminosulfonamide 15. With reference to Figure 1, aminosulfonamide core 15 can be synthesized by initially providing azidoepoxide 11 and subjecting it to nucleophilic addition with amine 12 to give aminoalcohol 13, which is subsequently converted 20 to sulfonamide 14 by reaction with 4-methoxybenzenesulfonyl chloride. The azide group of 14 is then reduced to provide aminosulfonamide 15, which can be used as a core for synthesizing numerous multidrug-resistant retroviral protease inhibitors of the present 25 invention.

Figure 2, which is a reaction scheme detailing the preparation of bicyclic alcohols, illustrates the synthesis of a preferred series of bicyclic ligands, particularly bis-tetrahydrofurans 25 and 26. With 30 reference to Figure 2, dihydrofuran 21 is treated with N-iodosuccinimide in the presence of propargyl alcohol to

give iodoether 22, which is cyclized to methylene-substituted bis-tetrahydrofuran 23. Ozonolysis of the exo-methylene residue of 23, followed by reduction, provides bicyclic racemic alcohol 24, which is resolved to 5 give, separately, bicyclic alcohol 25 and its enantiomeric acetate ester 26, which ester group of 26 is subsequently hydrolyzed to afford enantiomer 27.

Figures 3A and 3B, which are reaction schemes describing the preparation of two protease inhibitors, 10 illustrate the preparation of two preferred multidrug-resistant HIV protease inhibitors of the present invention. With reference to Figure 3A, compound 32 was synthesized by coupling succinimidocarbonate 31 with aminosulfonamide 15. Succinimidocarbonate 31 was prepared 15 by reacting optically pure bicyclic alcohol 25 with disuccinimidyl carbonate in the presence of triethylamine. Inhibitor 34, which possesses the enantiomeric bis-tetrahydrofuryl ligand (relative to inhibitor 32), was prepared in the same fashion, except that the enantiomeric 20 bicyclic alcohol 27 was used instead of alcohol 25, as illustrated in Figure 3B.

The following examples further illustrate the present invention but, of course, should not be construed as in 25 any way limiting its scope.

#### Example 1

This example describes the synthesis of exemplary epoxide 11 (Figure 1), which is used as an intermediate 30 in the synthesis of a particular series of compounds within the scope of the present invention.

Anhydrous CuCN (4.86 g, 54 mmol) was added to a solution of butadiene monooxide (38 g, 540 mmol) in anhydrous tetrahydrofuran (1.2 L) and the resulting mixture was stirred at -78°C. Commercial phenyl 5 magnesium bromide solution (Aldrich) in ether (65 mmol) was added dropwise over a period of 10 min. The resulting reaction mixture was then allowed to warm to 0 °C and it was continued to stir until the reaction mixture was homogeneous. After this period, the reaction 10 mixture was cooled to -78 °C and 0.58 mole of phenylmagnesium bromide solution in ether was added dropwise for 30 min. The reaction mixture was allowed to warm to 23 °C for 1 h. The reaction was quenched by slow addition of saturated aqueous NH<sub>4</sub>Cl (120 mL) followed by 15 NH<sub>4</sub>OH (70 mL), saturated NH<sub>4</sub>Cl (500 mL) and then H<sub>2</sub>O (300 mL). The aqueous layer was thoroughly extracted with ethyl acetate (2 x 300 mL). The combined organic layers were dried over anhydrous Na<sub>2</sub>SO<sub>4</sub>, filtered, and concentrated under reduced pressure. The residue was 20 distilled under vacuum (0.12 torr) at 95 °C to give *trans*-4-phenyl-2-butene-1-ol (75.6 g).

To a suspension of powdered 4Å molecular sieves (6.6 g) in anhydrous methylene chloride (750 mL), titanium tetrakisopropoxide (Aldrich, 3.2 mL) and then diethyl D- 25 tartrate (2.3 mL) were added. The resulting mixture was cooled to -22 °C and tert-butylhydroperoxide solution in isooctane (Aldrich, 430 mmol) was added over a period of 10 min. The mixture was stirred an additional 30 min and then a solution of *trans*-4-phenyl-2-butene-1-ol (32.6 g, 30 213 mmol), in anhydrous methylene chloride (120 mL), was added dropwise over a period of 40 min at -22 °C. The

reaction mixture was then aged in a freezer at -22 °C for 24 h. After this period, water (100 mL) was added to the reaction mixture at -22 °C and the mixture was allowed to warm to 0 °C. After stirring at 0 °C for 45 min, 20% NaOH in brine (20 mL) was added. The resulting mixture was then allowed to warm to 23 °C and was stirred at that temperature for 1 h. After this period, the layers were separated and the aqueous layer was extracted with methylene chloride (2 x 200 mL). The combined organic layers were dried over anhydrous Na<sub>2</sub>SO<sub>4</sub> and concentrated under reduced pressure. The residue was diluted with toluene (800 mL) and then evaporated under reduced pressure. The residue was chromatographed over silica gel (35% ethyl acetate in hexane as eluent) to provide (2R, 3R)-epoxy-4-phenylbutan-1-ol (21.8 g).

To a solution of titanium isopropoxide (12 mL) in anhydrous benzene (250 mL) was added azidotrimethylsilane (11 mL) and the resulting mixture was refluxed for 6 h. A solution of (2R,3R)-epoxy-4-phenylbutan-1-ol (5.32 g) in anhydrous benzene (25 mL) was added to the above refluxing mixture. The resulting mixture was refluxed for addition 25 min. After this period, the reaction mixture was cooled to 23 °C and the reaction was quenched with aqueous 5% H<sub>2</sub>SO<sub>4</sub> (400 mL). The resulting mixture was stirred for 1 h and the layers were separated and the aqueous layer was extracted with ethyl acetate (2 x 300 mL). The combined organic layers were washed with saturated NaHCO<sub>3</sub> (200 mL), dried over Na<sub>2</sub>SO<sub>4</sub> and concentrated under reduced pressure to afford the (2S,3S)-2-hydroxy-3-azido-4-phenylbutan-1-ol (5.1 g) as a white solid (mp 81-82 °C).

To a stirred solution of the azidodiol (5.1 g) in chloroform (100 mL) at 23 °C, 2-acetoxyisobutyryl chloride (Aldrich, 5mL) was added. The resulting reaction mixture was stirred at 23 °C for 8 h. The 5 reaction was quenched by addition of saturated sodium bicarbonate (100 mL) and the resulting mixture was stirred 30 min. The layers were separated and the aqueous layer was extracted with chloroform (2 x 200 mL). The combined organic layer was extracted with chloroform 10 (2 x 200 mL). The combined organic layers were dried over  $\text{Na}_2\text{SO}_4$  and evaporated under reduced pressure. The resulting residue was dissolved in anhydrous THF (50 mL) and solid NaOMe (2.1 g) was added. The mixture was stirred for 4 h at 23 °C and after this period, the 15 reaction was quenched with saturated  $\text{NH}_4\text{Cl}$  (50 mL). The resulting mixture was extracted with ethyl acetate (2 x 200 mL). The combined organic layers were dried over anhydrous  $\text{Na}_2\text{SO}_4$  and concentrated under reduced pressure to give a residue, which was chromatographed over silica 20 gel (10% ethyl acetate in hexanes) to afford the 3(S)-azido-(1,2R)-epoxy-4-phenylbutane 11 (3.3 g) as an oil:  $^1\text{H}$  NMR (300 MHz):  $\text{CDCl}_3$ ;  $\delta$  7.4-7.2 (m, 5H,), 3.6 (m, 1H), 3.1 (m, 1H), 2.95 (dd, 1H,  $J$  = 4.6, 13.9 Hz), 2.8 (m, 3H).

25

#### Example 2

This example illustrates the synthesis of azidoalcohol 13 (Figure 1), which can be used as an intermediate in the synthesis of a preferred series of 30 the compounds of the present invention.

To a stirred solution of above azidoepoxide 11 (700 mg, 3.7 mmol) in isopropanol (70 mL) was added isobutyl amine (Aldrich, 0.74 mL 7.4 mmol) and the resulting mixture was heated at 80 °C for 12 h. After this period, 5 the reaction mixture was concentrated under reduced pressure and the residue was chromatographed over silica gel to provide azidoalcohol 13 (800 mg) as an oil.

#### Example 3

10 This example illustrates the synthesis of azidosulfonamide 14, the structure of which is shown in Figure 1.

To a stirred solution of 13 (600 mg, 2.28 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (20 mL) was added 4-methoxybenzenesulfonyl chloride 15 (Aldrich, 530 mg, 2.52 mmol) and saturated aqueous NaHCO<sub>3</sub> (6 mL). The resulting heterogeneous mixture was stirred at 23 °C for 12 h. The reaction was diluted with CH<sub>2</sub>Cl<sub>2</sub>, and the layers were separated. The organic layer was washed with brine, dried over anhydrous magnesium sulfate 20 and concentrated to dryness. The residue was chromatographed over silica gel (25% ethyl acetate/hexane) to provide 900 mg of azidosulfonamide 14.

#### Example 4

25 This example illustrates the preparation of aminosulfonamide 15 via reduction of azidosulfonamide 14, as shown in Figure 1.

A solution of 14 (1.53 g) in THF (45 mL), MeOH (10 mL) and acetic acid (0.5 mL), was shaken with 10% 30 palladium on carbon catalyst (200 mg) at 50 psi hydrogen pressure for 2 h. Removal of the catalyst by filtration

over celite and concentration under reduced pressure gave a crude residue, which was diluted with  $\text{CH}_2\text{Cl}_2$  (100 mL), and was washed successively with saturated aqueous  $\text{NaHCO}_3$  and brine. The organic layer was dried over  $\text{MgSO}_4$  and 5 concentrated to give the corresponding aminosulfonamide 15 (1.2 g).

#### Example 5

10 This example demonstrates the synthesis of trans-2-(propargyloxy)-3-iodotetrahydrofuran 22 (Figure 2).

To a stirred, ice-cold suspension of 15 g (66.6 mmol) of N-iodosuccinimide in 150 mL of  $\text{CH}_2\text{Cl}_2$ , was added a mixture of dihydrofuran 21 (66.6 mmol, 4.67 g, 5.1 mL) and propargyl alcohol (100 mmol, 5.0 g, 5.2 mL) of in 15 50 mL of  $\text{CH}_2\text{Cl}_2$ , over 20 min. After warming to 24 °C with stirring over 2 h, 200 mL of water were added and the stirring continued for 1 h. The layers were separated and the aqueous layer was extracted with 2 x 100 mL of  $\text{CH}_2\text{Cl}_2$ . The combined organic extracts were washed with 20 brine solution containing small amount of  $\text{Na}_2\text{S}_2\text{O}_5$  (70 mg), dried over anhydrous  $\text{Na}_2\text{SO}_4$ , filtered, and concentrated. Chromatography over silica gel using 30% ethyl acetate in hexane afforded (15.4 g, 92%) the title iodoether 22 as an oil.

25

#### Example 6

This example illustrates the synthesis of ( $\pm$ )-(3aR, 6aS) and (3aS, 6aR)-3-methylene-4H-hexahydrofuro-[2,3-b]furan 23, as shown in Figure 2.

30 To a refluxing solution of (20.7 mL, 77 mmol) tributyltin hydride containing AIBN (100 mg) in toluene

(200 mL) was added dropwise a solution of 15.4 g (61 mmol) of iodotetrahydrofuran 22 in toluene (50 mL) over a period of 1 h. The resulting mixture was stirred at reflux for an additional 4 h (monitored by TLC). The 5 mixture was then cooled to 23 °C and concentrated under reduced pressure. The residue was partitioned between petroleum ether and acetonitrile (200 mL of each) and the acetonitrile (lower) layer was concentrated. The residue was purified by chromatography on silica gel, using 10% 10 ethyl acetate in hexane as the eluent to provide the title product 23 (5.84 g, 76%) as an oil.

#### Example 7

This example demonstrates the synthesis of (±)-(3S, 15 3aRS, 6aS) and (3R, 3aS, 6aR)-3-hydroxy-4H-hexahydrofuro[2,3-b]furan 24, as shown in Figure 2.

A stream of ozone was dispersed into a solution of 15 (5.84 g, 46.4 mmol) at -78 °C in 150 mL of methanol and 150 mL of  $\text{CH}_2\text{Cl}_2$  for 30 min. The resulting blue 20 solution was purged with nitrogen until colorless, then quenched with 20 mL of dimethyl sulfide and the resulting mixture was allowed to warm to 23 °C. The mixture was concentrated under reduced pressure to afford the crude ketone. The resulting crude ketone was dissolved in 25 ethanol (50 mL) and the solution was cooled to 0 °C and sodium borohydride (2.1 g, 55.6 mmol) was added. The reaction mixture was stirred for an additional 2 h at 0 °C and then quenched with 10% aqueous citric acid (10 mL). The resulting mixture was concentrated under 30 reduced pressure and the residue was partitioned between ethyl acetate and brine. The layers were separated and

the aqueous layer was extracted with ethyl acetate (2 x 100 mL). The combined organic layers were dried over anhydrous-Na<sub>2</sub>SO<sub>4</sub> and concentrated carefully under reduced pressure. The resulting residue was chromatographed over 5 silica gel using 30% ethyl acetate in hexane as the eluent to furnish (4.52 g, 75%) the title racemic alcohol 24 as an oil.

Example 8

10 This example illustrates the preparation of immobilized Amano Lipase 30, which was used to resolve racemic aminoalcohol 24 (Figure 2).

Commercially available 4 g of Celite® 521 (Aldrich) was loaded on a buchner funnel and washed successively 15 with 50 mL of deionized water and 50 mL of 0.05 N phosphate buffer (pH = 7.0; Fisher Scientific). The washed celite was then added to a suspension of 1 g of Amano lipase 30 in 20 mL of 0.05 N phosphate buffer. The resulting slurry was spread on a glass dish and allowed 20 to dry in the air at 23 °C for 48 h (weight 5.4 g; water content about 2% by Fisher method).

## Example 9

This example demonstrates the synthesis of (3R,3aS, 6aR) 3-hydroxyhexahydrofuro[2,3-b]furan 25 by immobilized lipase catalyzed acylation, as illustrated in Figure 2.

5 To a stirred solution of reacemic alcohol 24 (2 g, 15.4 mmol) and acetic anhydride (4 g, 42.4 mmol) in 100 mL of DME was added 2.7 g (about 25% by weight of lipase PS30) of immobilized Amano lipase and the resulting suspension was stirred at 23 °C. The reaction was

10 monitored by TLC and <sup>1</sup>H NMR analysis until 50% conversion was reached. The reaction mixture was filtered and the filter cake was washed repeatedly with ethyl acetate. The combined filtrate was carefully concentrated in a rotary evaporator, keeping the bath temperature below 15

15 °C. The residue was chromatographed over silica gel to provide 843 mg (42%) of 25 (95% ee;  $\alpha_D^{23}$  -11.9°, MeOH); <sup>1</sup>H-NMR (CDCl<sub>3</sub>) δ 1.85 (m, 2H), 2.3 (m, 1H), 2.9 (m, 1H), 3.65 (dd, J=7.0, 9.1, 1H), 3.85-4.0 (m, 3H), 4.45 (dd, J=6.8, 14.6, 1H), 5.7 (d, J=5.1, 1H); also, 1.21 g of 26

20 after washing with 5% aqueous sodium carbonate (45%,  $\alpha_D^{23}$  +31.8°, MeOH); <sup>1</sup>H-NMR (CDCl<sub>3</sub>) δ 1.85-2.1 (m, 2H), 2.1 (s, 3H), 3.1 (m, 1H), 3.75 (dd, J=6.6, 9.2, 1H), 3.8-4.1 (m, 3H), 5.2 (dd, J=6.4, 14.5, 1H), 5.7 (d, J=5.2, 1H). Acetate 26 was dissolved in THF (5mL) and 1 M aqueous

25 LiOH solution (20 mL) was added to it. The resulting mixture was stirred at 23°C for 3 h and the reaction was extracted with chloroform (3 x 25 mL). The combined organic layers were dried over anhydrous Na<sub>2</sub>SO<sub>4</sub> and evaporated under reduced pressure. The residue was

30 chromatographed over silica gel to provide 733 mg of 27 (97% ee;  $\alpha_D^{23}$  -12.5°, MeOH).

**Example 10**

This example demonstrates the synthesis of activated carbonates 31 and 33, as illustrated in Figures 3A and 5 3B.

To a stirred solution of [3R,3aS, 6aS]-3-hydroxyhexahydrofuro[2,3-b]furan 25 (65 mg, 0.5 mmol) in dry CH<sub>3</sub>CN (5 mL) at 23°C were added disuccinimidyl carbonate (192 mg, 0.75 mmol) and triethylamine (0.25 10 mL). The resulting mixture was stirred at 23°C for 12 h. The reaction was quenched with saturated aqueous NaHCO<sub>3</sub> (10 mL) and the mixture was concentrated under reduced pressure. The residue was extracted with CH<sub>2</sub>Cl<sub>2</sub> (2 x 25 mL) and the combined organic layers were washed with 15 brine (10 mL) and dried over anhydrous Na<sub>2</sub>SO<sub>4</sub>. Evaporation of the solvent under reduced pressure gave a residue, which was chromatographed over silica gel (50% ethyl acetate/hexane) to furnish (3R, 3aS, 6aR) 3-hydroxyhexahydrofuro[2,3-b]furanyl-succinimidyl carbonate 20 31 (70 mg) as a brown oil. Carbonate 33 (65 mg) was prepared from 60 mg of alcohol 27 by following a similar procedure.

**Example 11**

25 This example illustrates the preparation of multidrug-resistant HIV inhibitor 32, as illustrated in Figure 3A.

To a stirred solution of amine 15 (82 mg, 0.2 mmol) in dry CH<sub>2</sub>Cl<sub>2</sub> (5 mL) was added succinimidyl carbonate 31 30 (55 mg, 0.18 mmol). The resulting solution was stirred at 23°C for 12 h. After this period, the reaction was

quenched with saturated aqueous NaHCO<sub>3</sub> (10 mL) and diluted with CH<sub>2</sub>Cl<sub>2</sub> (25 mL). The layers were separated and the organic layer was washed with brine (15 mL) and dried over anhydrous Na<sub>2</sub>SO<sub>4</sub>. Evaporation of the solvent under reduced pressure afforded a residue, which was purified by silica gel chromatography (75% ethyl acetate/hexane) to furnish compound 32 (85 mg) as a white solid (m.p 55-58°C). <sup>1</sup>H-NMR (CDCl<sub>3</sub>, 400 MHz); δ 7.71 (d, 2H, J=8.8 Hz), 7.29-7.20 (m, 5H), 6.99 (d, 2H, J=7.0 Hz), 5.65 (d, 1H, J=5.19), 5.01 (m, 2H), 3.95-3.82 (m, 7H), 3.69 (m, 2H), 3.0-2.7 (m, 6H), 1.85 (m, 1H), 1.64-1.45 (m, 3H), 0.90 (two d, 6H, J=6.5Hz, 6.6 Hz).

#### Example 12

15 This example illustrates the preparation of multidrug-resistant HIV inhibitor 33, as illustrated in Figure 3B.

Carbonate 33 (55 mg) was reacted with amine 15 (82 mg, 0.2 mmol) according to the procedure mentioned above 20 to provide compound 34 (81 mg). <sup>1</sup>H-NMR (CDCl<sub>3</sub>, 300 MHz); δ 7.69 (d, 2H, J=8.8 Hz), 7.28-7.21 (m, 5H), 6.87 (d, 2H, J=5.84 Hz), 5.67 (d, 1H, J=5.46 Hz), 5.0 (m, 2H), 3.86-3.81 (m, 7H), 3.58 (dd, 2H, J=6.6 Hz, 3.6 Hz, 3.17-2.73 (m, 6H), 2.17-1.83 (m, 4H), 0.90 (two d, 6H, 25 J=6.5Hz, 6.6 Hz).

## Example 13

This example describes the protocol for the sensitive continuous fluorogenic assay for HIV protease of the present invention and its application. Using this 5 assay, the inhibitory activity of compound 32 (Fig. 3A) was tested against the proteases of wild-type HIV-1 (WT) and various mutant enzymes: D30N, V32I, I84V, V32I/I84V, M46F/V82A, G48V/L90M, V82F/I84V, V82T/I84V, V32I/K45I/F53L/A71V/I84V/L89M, 10 V32I/L33F/K45I/F53L/A71V/I84V, and 20R/36I/54V/71V/82T, which protease enzymes are available from Dr. John W. Erickson, Structural Biochemistry Program, SAIC Frederick, P.O. Box B, Frederick, MD 21702-1201, upon written request. The inhibition constant for wild-type 15 HIV-1,  $K_{i\text{act}}/K_{i\text{wt}}$  ratio, and vitality were measured. (See Gulnik et al., *Biochemistry*, 34, 9282-9287 (1995). Protease activity was measured using the fluorogenic substrate Lys-Ala-Arg-Val-Tyr-Phe(NO<sub>2</sub>)<sub>2</sub>-Glu-Ala-Nle-NH<sub>2</sub> (Bachem Bioscience, Inc.). (See Peranteau et al., D.H. 20 (1995) *Anal. Biochem.*).

Typically, 490  $\mu$ l of 0.125 M ACES-NaOH buffer, pH 6.2, containing 1.25 M (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>, 6.25 mM DTT and 0.1% PEG-8000 was mixed with 5  $\mu$ l of titrated protease (final concentration 1-5 nM) and incubated 3 min at 37 °C. The 25 reaction was initiated by the addition of 5  $\mu$ l of substrate stock solution in water. Increase in fluorescence intensity at the emission maximum of 306 nm (excitation wavelength was 277 nm) was monitored as a function of time using Aminco Bowman-2 luminescence 30 spectrometer (SLM Instruments, Inc.). The initial rate of hydrolysis was calculated by second degree polynomial

fit using SLM AB2 2.0 operating software. Kinetic parameters were determined by nonlinear regression-fitting of initial rate versus substrate concentration data to the Michaelis-Menten equation using program

5 Enzfiter version 1.05.

For inhibition studies, inhibitors were prepared as stock solutions at different concentrations in dimethylsulfoxide. In a typical experiment 485  $\mu$ l of 0.125 M ACES-NaOH buffer, pH 6.2, containing 1.25 M 10  $(\text{NH}_4)_2\text{SO}_4$ , 6.25 mM DTT AND 0.1% PEG-8000, was mixed with 5  $\mu$ l of inhibitor stock solution and 5  $\mu$ l of titrated protease (final concentration of 1-5 nM) and preincubated 3 min at 37 °C. The reaction was initiated by the addition of 5  $\mu$ l of substrate stock solution in water.

15 For data analysis, the mathematical model for tight-binding inhibitors was used. (See Williams and Morrison (1979), In: Methods of Enzymol. 63, (ed. D.L. Purich), 437-467, Academic Press, NY, London). The data were fitted by nonlinear regression analysis to the equation:

20  $V = V_0 / 2E_t \left( \{ [K_i(1+S/K_m) + I_t - E_t]^2 + 4K_i(1+S/K_m)E_t \}^{1/2} - [K_i((1+S/K_m) + I_t - E_t)] \right)$  with the program Enzfiter (version 1.05), where  $V$  and  $V_0$  are initial velocities with and without inhibitor, respectively,  $K_m$  is a Michaelis-Menten constant, and  $S$ ,  $E_t$  and  $I_t$  are the concentrations of substrate, active 25 enzyme, and inhibitor, respectively. Biochemical fitness for each mutant was determined by comparing the biochemical vitality of each mutant ( $\text{vitality}_{\text{mut}}$ ) with the biochemical vitality of the wild-type reference ( $\text{vitality}_{\text{wt}}$ ), according to the formula

30  $(\text{vitality}_{\text{mut}}) / (\text{vitality}_{\text{wt}})$ ,

wherein vitality is  $(K_i)(k_{cat}/K_m)$ . The results are shown below in Table 1.

Table 1

Enzyme	Compound 32		
	$K_i$ (pM)	$K_{I-mut} / K_{I-wt}$	Biochemical Fitness
WT	14	1	1
D30N	<5	0.33	0.3
V32I	8	0.57	0.5
I84V	40	2.85	1
V32I/I84V	70	5	0.7
M46F/V82A	<5	0.33	0.1
G48V/L90M	<5	0.33	0.1
V82F/I84V	7	0.5	0.1
V82T/I84V	22	1.57	0.1
V32I/K45I/F53L/A71V/I84V/L89M	31	2.2	0.1
V32I/L33F/K45I/F53L/A71V/I84V	46	3.3	0.1
20R/36I/54V/71V/82T	31	2.2	0.1

5 The above results demonstrate that compound 32 is a potent inhibitor of multiple HIV protease mutants that contain the primary or key drug resistance mutations. These data predict that compound 32 will have potent and broad-spectrum multidrug-resistant antiretroviral

10 activity. Moreover, the biochemical fitness of each mutant relative to wild type is equal to or less than one in the presence of compound 32. Based on this fitness profile, it is believed that drug resistant viruses containing the characteristic mutations assayed herein

15 will not emerge from the wild-type in the presence of compound 32.

## Example 14

This example illustrates the potent and broad-spectrum multidrug-resistant antiretroviral activity of an exemplary compound of the present invention.

Compound 32, shown in Figure 3A, was tested side-by-side with four other known HIV-1 protease inhibitors against various wild-type HIV-1 strains (HIV-1<sub>MRSL04pre</sub>, HIV-1<sub>LAI</sub>, and HIV-1<sub>BAL</sub>), and mutant multidrug-resistant HIV-1 strains clinically isolated from eight different patients who had received numerous antiviral drugs, either singly or in combination. The patients from which the mutant strains were isolated had a history of anti-HIV therapy with a variety of different drugs such as, for example, ritonavir, saquinavir, indinavir, amprenavir, AZT, ddI, ddC, d4T, 3TC, ABV (abacavir), DLV (delavirdine), and PFA (foscarnet). The patient profiles are shown below in Table 2.

Table 2

Patient/ Isolate Code	CD4 <sup>+</sup> (/mm <sup>3</sup> )	HIV-1 RNA level (copies/mL)	Months on Antiviral Therapy	Prior and Present Anti- HIV Therapy
1	361	246,700	64	AZT, ddI, ddC, d4T, 3TC, ABV, IDV, RTV, SQV, AMV, DLV
2	3	553,700	46	AZT, ddI, ddC, d4T, 3TC, ABV, IDV, SQV, AMV
3	108	42,610	39	AZT, ddI, ddC, d4T, 3TC, ABV, IDV, SQV, AMV
4	560	60,000	81	AZT, ddI, ddC, U90, d4T, 3TC, ABV, IDV, SQV, AMV
5	-	-	32	AZT, ddI, ddC, d4T, 3TC, ABV, IDV, SQV, AMV
6	-	-	34	AZT, ddI, ddC, d4T, 3TC, ABV, IDV, SQV, AMV
7	-	-	83	AZT, ddI, ddC, d4T, 3TC, ABV, IDV, SQV, RTV, AMV
8	-	-	69	AZT, ddI, ddC, d4T, 3TC, PFA, ABV, IDV, SQV, AMV

The four known chemotherapeutic HIV protease inhibitors used for comparative purposes in this example have been utilized in actual human HIV chemotherapy, and are: Ritonavir ("RTV," Abbott Laboratories); Indinavir 5 ("IDV," Merck Research Laboratories); Amprenavir (AMV, See Ghosh et al., *Bioorg. Med. Chem. Lett.*, 8, 687-690 (1998)); and Saquinavir ("SAQ", Roche Research Centre). The IC<sub>50</sub> values (μM) for all five compounds were determined with respect to wild-type and multidrug-resistant HIV-1. 10

To determine protease inhibitory activity against multidrug resistant HIV, the IC<sub>50</sub>'s were measured against a panel of clinically isolated mutant HIV isolates. The IC<sub>50</sub>'s were determined by utilizing the PHA-PBMC exposed 15 to HIV-1 (50 TCID<sub>50</sub> dose/1X10<sup>6</sup> PBMC) as target cells and using the inhibition of p24 Gag protein production as an endpoint.

The IC<sub>50</sub>'s were determined by utilizing the PHA-PBMC assay in which target cells are exposed to HIV-1 (50 20 TCID<sub>50</sub> dose/1X10<sup>6</sup> PBMC) and inhibition of p24 Gag protein production is used as an endpoint. All drug sensitivities were performed in triplicate. In order to determine whether the HIV isolates were syncitium inducing (SI) or non-syncitium inducing (NSI), an aliquot 25 of viral stock supernatant, containing 100 TCID<sub>50</sub>, was cultured with 1 X 10<sup>5</sup> MT-2 cells in a 12-well plate. Cultures were maintained for four weeks and were examined for syncytium formation twice a week. The results are shown below in Table 3.

Table 3

Pheno-type	Patient/ Isolate code (See Table 2)	IC <sub>50</sub> (μM)				
		RTV	IDV	AMV	SAQ	Compound 32
SI	HIV-1 <sub>BB104pre</sub>	0.055	0.013	0.021	0.01	<0.001
SI	HIV-1 <sub>BB</sub>	0.0047	0.019	0.019	0.0054	0.0004
NSI	HIV-1 <sub>BB</sub>	0.018	0.0056	0.014	0.0037	0.0004
		1	>1	0.29	0.29	0.002
		2	>1	0.24	0.24	<0.001
		3	>1	0.46	0.33	<0.001
		4	>1	0.24	0.4	0.001
		5	>1	0.8	0.28	0.002
		6	>1	0.37	0.11	<0.001
		7	>1	>1	0.42	0.12
		8	>1	>1	0.22	0.009

The above IC<sub>50</sub>'s clearly demonstrate the broad-spectrum and extraordinarily potent activity of compound 5 32 against wild-type HIV-1 and the eight different multidrug-resistant clinical isolates tested as was predicted from the biochemical fitness profiles in Example 13. For example, compound 32 exhibits nanomolar and sub-nanomolar potency against all the multidrug-resistant 10 strains tested, whereas Ritonavir, a reasonably potent wild-type inhibitor, is virtually inactive toward the resistant viruses. Moreover, compound 32 is about 9 to about 150 times more potent against the multidrug-resistant viruses than Saquinavir, one of the most potent 15 known compounds against known multidrug-resistant strains of HIV-1. Patients with viral plasma loads greater than 10,000 RNA copies/mm<sup>3</sup> are at risk for developing fatal AIDS complications. There are no effective therapeutic options currently available for these patients infected 20 with these multidrug resistant viruses. Compound 32 and analogs thereof are predicted to be potent in preventing the selection of these viral strains in vivo.

**Example 15**

This example demonstrates the wild-type antiretroviral activity of the compounds of the present  
5 invention.

It is predicted that the activity of the present inventive compounds against wild-type HIV protease correlates with of antiretroviral activity against multidrug-resistant HIV. Numerous compounds of the  
10 present invention were tested against wild-type HIV (See,, Ghosh et al., *J. Bioorg. Med. Chem. Lett.*, 8, 6870690 (1998)). Exemplary compounds, which demonstrate potent wild-type HIV protease activity, are shown below in Table 4.

Table 4

A	R <sup>3</sup>	R <sup>5</sup>	Comments		
			K <sub>i</sub> (nM)	KD <sub>50</sub> (nM)	
	Ph		2.1	4.5	Compound 32 (Fig. 3A)
	Ph		1.1	1.4	Compound 34 (Fig. 3B)
	Ph		1.2	3.5	
	Ph		2.2	4.5	
	Ph				
	Ph	<img alt="Chemical structure of R5: 4-phenylpropyl group			

It is believed that the above compounds in Table 4 will prevent the emergence of resistance in an HIV-infected human.

**Example 16**

5 This example demonstrates the oral absorption of compound 32 in an *in vivo* experimental model.

Compound 32 was orally administered to a rat at a dose of about 40 mg per kg body mass, using a PEG 300 vehicle as a carrier. The plasma blood levels of compound 32 were measured 10 over a 24 h period after oral administration. The results are shown in Table 5 below.

Table 5

Time After Administration		Plasma Concentration	
Hours	Minutes	(nM)	(ng/mL)
0.28	17	1598	898
1.00	60	878	493
2.07	124	626	352
4.01	240	670	377
6.01	360	594	334
8.05	483	1115	627
12.04	722	246	138
14.08	845	102	57
24.00	1440	82	46

15 These results demonstrate that compound 32 maintains high blood levels (e.g., nearly 0.6 uM after 6 hours) long after oral administration. Although applicants do not wish to abound by any one particular theory, it is believed that the non-peptide structure of the compounds of the present invention 20 make them less prone to biological (e.g., enzymatic) degradation, and thereby contribute to their prolonged blood levels after oral administration. From these data, the compounds of the present invention are predicted to have

excellent oral bioavailability in humans, and maintain therapeutically significant blood levels over prolonged periods after oral administration.

5 Example 17

This example demonstrates the influence of human protein binding on the antiviral activity of compound 32. Several potent and orally bioavailable HIV protease inhibitors failed to have *in vivo* antiviral efficacy. These failures have been 10 ascribed, but not definitively proven, to be due to excessive binding to human plasma proteins, particularly serum albumin and AAG. The protein binding against human alpha acid glycoprotein (AAG, 10  $\mu$ M) and against human serum albumin (HAS, 300  $\mu$ M) were compared for compound 32 and amprenavir, a 15 structurally related analog that is an FDA approved drug. The results are shown in Table 6.

Table 6

Compound	IC <sub>50</sub> ( $\mu$ M)		
	(-)	AAG	Alb
32	0.0015(1X)	0.0022(1.5X)	0.003(2X)
amprenavir	0.029(1X)	0.18(6X)	0.021(1X)

These data demonstrate that the presence of AAG and HAS in 20 physiologically excessive amounts does not adversely affect the antiviral activity of compound 32. From these data, the affinity of compound 32 for human AAG and HSA is predicted to be actually lower than that for amprenavir, a known drug. From these data, the compounds of the present invention are expected 25 to have excellent *in vivo* efficacy in humans, and maintain therapeutically significant levels over prolonged periods of time.

## Example 18

This example describes the inhibitory activity of compounds 35 (Fig. 5A), 36 (Fig. 5B), 37 (Fig. 5C) and 38 (Fig. 5D). In accordance with the technique disclosed in Example 13 above, the 5 inhibitory activity of these compounds was tested against proteases of the wild-type HIV-1. Compound 36, 37 and 38 were also tested against proteases containing the deleterious drug resistance associated mutations V82F/I84V and G48V/V82A. Fitness was determined in accordance with Example 13. The results of 10 these experiments are shown below in Table 7.

Table 7

COMPOUND	ENZYME	K <sub>i</sub> (pM)	K <sub>i-wt</sub> /K <sub>i-mut</sub>	Fitness
35	WT	81	1	
36	WT	5<		
	V82F/I84V	24.4	>4.9	>0.8
	G48V/V82A	15.3	>3.0	>0.8
37	WT	12	1	
	V82F/I84V	25.7	2.1	0.3
	G48V/V82A	64	5.3	1.4
38	WT	>5		
	V82F/I84V	66.8	>13	>2.1
	G84V/V82A	34	> 6.8	>1.8

15 These results further demonstrate compounds of the present invention that are potent inhibitors against mutant proteases. Based on the fitness profile, it is believed that drug resistant viruses containing the characteristic mutations assayed herein will not emerge from the wild-type in the 20 presence of compound 37.

## Example 19

This example further demonstrates the broad-spectrum and potent activity of exemplary compounds of the present invention 25 against multidrug-resistant clinical isolates.

The  $IC_{50}$  values ( $\mu M$ ) for all compounds 32, 35, 36, 37, and 38 were determined with respect to wild type clinical isolates HIV-1<sub>LAI</sub> and HIV-1<sub>BA-L</sub>. The latter is a monocyteotropic strain of HIV.

5 The  $IC_{50}$ 's for isolates HIV-1<sub>LAI</sub> and HIV-1<sub>BA-L</sub> were determined by exposing the PHA-simulated PBMC to HIV-1 (50 TCID<sub>50</sub> dose/1X10<sup>6</sup> PBMC), in the presence of various concentrations of compounds 32, 35, 36, 37 and 38, and using the inhibition of p24 Gag protein production as an endpoint on day 7 of culture ("p24 10 assay"). All drug sensitivities were performed in triplicate. The  $IC_{50}$ 's for isolate HIV-1<sub>LAI</sub> were also determined by exposing MT-2 cells ( $2 \times 10^3$ ) to 100 TCID<sub>50</sub>'s of HIV-1<sub>LAI</sub> cultured in the presence of various concentrations of compounds 32, 35, 36, 37 and 38. The  $IC_{50}$ 's were determined using the MTT assay on day 7 15 of culture. All sensitivities were determined in duplicate. The results are shown below in Table 8.

Table 8

Virus	Cell Type	Comp. 32	Comp. 35	Comp. 36	Comp. 37	Comp. 38
	/Assay	$IC_{50}$ ( $\mu M$ )				
HIV-1 <sub>LAI</sub>	MT-2/MTT	0.00022	0.028	0.017	0.0053	0.028
HIV-1 <sub>LAI</sub>	PBMC/p24	0.00022	0.020	0.034	0.0027	0.0080
HIV-1 <sub>BA-L</sub>	PBMC/p24	0.00033	0.013	0.038	0.0030	0.0093

20 These results demonstrate the potent antiretroviral activity of particular compounds of the present invention.

## Example 20

This example further illustrates the potent and broad-spectrum multidrug-resistant antiretroviral activity of an exemplary compound of the present invention.

5 Compound 32, shown in Figure 3A, was tested against various mutant multidrug-resistant HIV-1 strains clinically isolated from patients. These isolates were all taken from patients who failed therapy on one or more HIV protease inhibitors due to high level clinical resistance. All of these isolates exhibit  
10 high level phenotypic resistance in antiviral assays against many of the commonly use HIV protease inhibitor drugs. Compound 32 was tested against these multidrug-resistant clinical isolates side-by-side with known drugs that are commonly used in HIV antiviral therapy, including reverse transcriptase  
15 inhibitors such as AZT, 3TC, DDI, DDC, and D4T, and protease inhibitors such as Indinavir (Ind.), Nelfinavir (Nel.), Ritonavir (Rit.), and Saquinavir (Saq.). The IC<sub>50</sub>'s for compound 32 and the comparative drugs against the multidrug-resistant HIV-1 clinical isolates, and against wild-type HIV-1 (WT), are  
20 shown in Table 9a.

The mutant multidrug-resistant HIV-1 strains corresponding to each patient, numbered 9-35, were genetically analyzed in terms of the nucleic acid sequences of the protease (PR) and a portion of the reverse transcriptase (RT) genes from which  
25 mutations in these enzymes were determined. The mutations in the protease and reverse transcriptase of the multidrug-resistant viruses isolated from each patient are shown below in Table 9b.

Table 9a

Patient Isolate	IC <sub>50</sub> (μM)						Comp. 32
	AZT	3TC	DDI	DDC	D4T	Ind.	
9	0.01	0.39	0.7	0.15	0.91	1.087	0.53
10	0.02	1.35	1.7	0.37	1.29	>1.25	>0.3125
11	0.11	23.61	2.4	0.18	3.10	0.012	2.03
12	0.07	0.78	0.9	0.20	1.23	>1.25	>0.3125
13	0.17	1.04	0.5	<0.1221	0.78	>1.25	0.001
14	0.64	2.4	<0.1221	1.10	0.089	0.47	0.004
15	0.20	>31.25	2.2	0.32	1.10	0.265	0.003
16	0.97	27.98	3.5	0.57	1.81	0.384	0.011
17	>1.25	28.05	0.63	4.28	0.502	0.52	0.0031
18	0.55	>31.25	2.2	0.48	2.08	0.369	0.0022
19	>1.25	>31.25	36.6	6.80	35.63	0.784	0.0019
20	1.25	3.21	7.1	0.57	22.54	0.591	0.005
21	>1.25	1.69	1	0.38	3.28	1.250	0.032
22	1.02	>31.25	3.7	0.63	4.68	0.173	0.21
23	0.19	>31.25	1.8	0.28	1.00	0.461	0.008
24						0.28	0.004
25						1.82	0.008
26							0.0004
27	0.03	1.72	2.6	0.41	4.00	>1.25	0.0019
28	>1.25	2.08	2.8	0.36	5.44	1.040	>0.3125
29	>1.25	2.24	3.8	0.34	5.29	0.569	2.66
30	0.16	>31.25	2.8	0.24	2.52	0.270	>0.3125
31		>31.25	2.6	<0.1221	3.11	0.251	0.36
32	0.32	>31.25	8.4	0.91	2.41	0.223	0.50
33	0.51	>31.25	2.0	0.28	2.73	0.133	0.050
34	>1.25	>31.25	9.1	1.13	7.71	0.595	0.18
35	0.88	>31.25	17.0	2.46	18.13	0.509	0.059
(WT)	0.022	0.264	0.895	0.243	1.059	0.02	0.063
						0.031	0.012
						0.019	0.007

Table 9b

(Table 9b cont'd.)

(Table 98 cont'd.)

Table 9b (con't.)

Table 9b (cont'd.)

The results of this experiment further show the effectiveness of an exemplary compound of the present invention against a wide range of viral mutants compared to 5 other well-known inhibitors. These mutant viruses represent a panel of the most broadly cross resistant clinical isolates known to date based on their resistance to therapeutically used HIV protease inhibitors. Compound 32 was consistently potent against all of the clinically 10 isolated mutant viruses tested, and was significantly more potent against these multidrug resistant viruses than the comparative drugs which are currently used in human HIV-1 therapy. Compound 32 was ten to one-thousand times more potent against these viruses than even saquinavir, one of 15 the most potent known compounds against multidrug-resistant HIV-1. Based on the high potency, it is believed that these mutants will not only be inhibited, but also that these mutants would not be able to emerge if the compound is administered to a patient infected with a predecessor virus.

20

All of the references cited herein, including 25 patents, patent applications, and publications, are hereby incorporated in their entireties by reference.

While this invention has been described with an 30 emphasis upon preferred embodiments, it will be obvious to those of ordinary skill in the art that variations of the preferred embodiments may be used and that it is intended that the invention may be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications encompassed within

**the spirit and scope of the invention as defined by the following claims.**

## WHAT IS CLAIMED IS:

1. An assay for determining the biochemical fitness of a biochemical target of a mutant replicating biological entity relative to its predecessor,  
5 comprising:
  - obtaining said predecessor,
  - determining the biochemical vitality of said biochemical target of said predecessor in the presence of a compound capable of inhibiting said biochemical target  
10 of said predecessor,
  - determining the biochemical vitality of said biochemical target of said mutant replicating biological entity in the presence of said compound, and
  - comparing the biochemical vitality of said  
15 biochemical target of said mutant replicating biological entity relative to the biochemical vitality of said biochemical target of said predecessor.
2. The assay of claim 1, wherein said predecessor  
20 is an infectious microorganism.
3. The assay of claim 2, wherein said infectious microorganism is a virus.
- 25 4. The assay of claim 3, wherein said virus is a retrovirus.
5. The assay of claim 4, wherein said retrovirus is HIV-1 or HIV-2.

6. The assay of claim 2, wherein said infectious microorganism is a malarial parasite.

7. The assay of claim 6, wherein said malarial parasite is a plasmodium species.

8. The assay of claim 2, wherein said infectious microorganism is a bacterium.

10 9. The assay of claim 1, wherein said predecessor is a cancer cell.

10. The assay of claim 9, wherein said cancer replicating biological entity is a rapidly growing tumor cell.

11. The assay of any one of claims 1-10, wherein said biochemical target of said predecessor is an enzyme and said compound inhibits said enzyme of said predecessor.

12. The assay of any one of claims 3-5, wherein said biochemical target of said predecessor is a viral protease, a viral reverse transcriptase, a viral polymerase, a viral enzyme, or a viral protein.

13. The assay of claim 6 or 7, wherein said biochemical target of said malarial parasite is a plasmepsin, a plasmodial enzyme, or a protein.

14. The assay of any one of claims 1-10, wherein said biochemical target of said predecessor is an oligomer and said compound inhibits the oligomerization of said oligomer of said predecessor.

5

15. The assay of any one of claims 1-10, wherein said biochemical target of said predecessor is a protein and said compound inhibits a conformational change, ligand binding, or enzyme activity in said protein of 10 said predecessor.

16. The assay of claim 11, wherein:  
the biochemical vitality of the enzyme of said mutant replicating biological entity corresponds to  $K_{inh-mut}$ ,  $k_{cat-mut}$ , and  $K_M-mut$ , and said biochemical vitality of the 15 enzyme of said mutant replicating biological entity is defined by the relationship  $K_{inh-mut} (k_{cat-mut}/K_M-mut)$ , and the biochemical vitality of the enzyme of said predecessor corresponds to  $K_{inh-pred}$ ,  $k_{cat-pred}$ , and 20  $K_M-pred$ , and said biochemical vitality of the enzyme of said predecessor is defined by the relationship  $K_{inh-pred} (k_{cat-pred}/K_M-pred)$ , wherein  $K_{inh}$  is an inhibition constant of said compound,  $k_{cat}$  is the biochemical catalytic rate, and  $K_M$  is the 25 Michaelis constant.

17. The assay of claim 16, wherein  $K_{inh-mut}$ ,  $K_{inh-pred}$ ,  $k_{cat-mut}$ ,  $k_{cat-pred}$ ,  $K_M-mut$ , and  $K_M-pred$  are each measured.

30

18. The assay of claim 16 or 17, wherein  $K_{inh}$  is  $K_i$ .

19. The assay of claim 16 or 17, wherein  $K_{inh}$  is  $K_d$ .

20. A method of administering a therapeutic compound that inhibits a biochemical target of a disease-causing replicating biological entity, comprising:

identifying at least one mutant capable of evolving from said disease-causing replicating biological entity,

determining a first biochemical vitality of said biochemical target of said disease-causing replicating biological entity in the presence of a first compound capable of inhibiting said biochemical target of said disease-causing replicating biological entity,

determining a first biochemical vitality of said biochemical target of said mutant replicating biological entity in the presence of said first compound,

determining a second biochemical vitality of said biochemical target of said disease-causing replicating biological entity in the presence of at least one additional compound capable of inhibiting said biochemical target of said disease-causing replicating biological entity,

determining a second biochemical vitality of said biochemical target of said mutant in the presence of said of at least one additional compound,

determining a first biochemical fitness of said biochemical target of said mutant relative to said disease-causing replicating biological entity by comparing the first biochemical vitality of said biochemical target of said mutant with the first biochemical vitality of said biochemical target of said disease-causing replicating biological entity,

determining a second biochemical fitness of said biochemical target of said mutant relative to said disease-causing replicating biological entity by comparing the second biochemical vitality of said

5 biochemical target of said mutant with the second biochemical vitality of said biochemical target of said disease-causing replicating biological entity,

comparing the first biochemical fitness in the presence of said first compound with the second

10 biochemical fitness in the presence of said at least one additional compound, and

administering, from among said first and said at least one additional compounds, a therapeutic compound which produces the lowest value for said first or said

15 second biochemical fitness,

wherein said disease-causing replicating biological entity is less likely to develop resistance in the presence of said therapeutic compound.

20 21. The method of claim 20, wherein said replicating disease-causing replicating biological entity is an infectious microorganism.

22. The method of claim 21, wherein said infectious

25 microorganism is a virus.

23. The method of claim 22, wherein said virus is a retrovirus.

30 24. The method of claim 23, wherein said retrovirus is HIV or HIV-2.

25. The method of claim 21, wherein said infectious microorganism is a malarial parasite.

5 26. The method of claim 25, wherein said malarial parasite is a plasmodium species.

27. The method of claim 21, wherein said infectious microorganism is a bacterium.

10

28. The method of claim 20, wherein said replicating disease-causing replicating biological entity is a cancer cell.

15 29. The method of claim 28, wherein said cancer cell is a rapidly growing tumor cell.

30. The method of any one of claims 20-29, wherein said biochemical target of said disease-causing  
20 replicating biological entity is an enzyme and said compound inhibits said enzyme of said disease-causing replicating biological entity.

31. The method of any one of claims 22-24, wherein  
25 said biochemical target of said disease-causing replicating biological entity is a viral protease, a viral reverse transcriptase, a viral polymerase, a viral enzyme, or a viral protein.

32. The method of claim 25 or 26, wherein said biochemical target of said malarial parasite is a plasmepsin, a plasmodial enzyme, or a protein.

5 33. The method of any one of claims 20-29, wherein said biochemical target of said disease-causing replicating biological entity is an oligomer and said compound inhibits the oligomerization of said oligomer of said disease-causing replicating biological entity.

10

34. The method of any one of claims 20-29, wherein said biochemical target of said disease-causing replicating biological entity is a protein and said compound inhibits a conformational change, ligand binding, or enzyme activity in said protein of said disease-causing replicating biological entity.

35. The method of claim 30, wherein:  
the biochemical vitality of the enzyme of said  
20 mutant corresponds to  $K_{inh-mut}$ ,  $k_{cat-mut}$ , and  $K_m-mut$ , and said biochemical vitality of the enzyme of said mutant is defined by the relationship  $K_{inh-mut} (k_{cat-mut}/K_m-mut)$ , and  
the biochemical vitality of the enzyme of said disease-causing replicating biological entity corresponds  
25 to  $K_{inh-pred}$ ,  $k_{cat-pred}$ , and  $K_m-pred$ , and said biochemical vitality of the enzyme of said disease-causing replicating biological entity is defined by the relationship  $K_{inh-pred} (k_{cat-pred}/K_m-pred)$ ,  
wherein  $K_{inh}$  is an inhibition constant of said compound,  
30  $k_{cat}$  is the biochemical catalytic rate, and  $K_m$  is the Michaelis constant.

36. The method of claim 35, wherein  $K_{inh-mut}$ ,  $K_{inh-pred}$ ,  $k_{cat-mut}$ ,  $k_{cat-pred}$ ,  $K_{M-mut}$ , and  $K_{M-pred}$  are each measured.

5 37. The method of claim 35 or 36, wherein  $K_{inh}$  is  $K_i$ .

38. The method of claim 35 or 36, wherein  $K_{inh}$  is  $K_d$ .

10 39. The assay of claim 1, wherein said predecessor is a wild-type HIV strain and said mutant has at least one mutation in the biochemical target thereof.

15 40. The method of claim 20, wherein said replicating disease-causing replicating biological entity is a wild-type HIV strain and said mutant has at least one mutation in the biochemical target thereof.

20 41. The assay of claim 1, wherein said predecessor has at least one mutation in the biochemical target thereof, and said mutant has at least two mutations in the biochemical target thereof.

25 42. The method of claim 20, wherein said replicating disease-causing replicating biological entity has at least one mutation in the biochemical target thereof, and said mutant has at least two mutations in the biochemical target thereof.

30 43. The method of claim 39 or 40, wherein said mutant has at least one active site mutation.

44. The method of claim 41, wherein said predecessor or said mutant has at least one active site mutation.

5 45. The method of claim 42, wherein said disease-causing replicating biological entity or said mutant has at least one active site mutation.

10 46. A continuous fluorogenic assay for measuring the anti-HIV protease activity of a protease inhibitor, which method comprises:

15 adding a solution of HIV protease to at least a portion of a substrate stock solution, in which the substrate has the formula Ala-Arg-Val-Tyr-Phe(NO<sub>2</sub>)-Glu-

15 Ala-Nle-NH<sub>2</sub>, to provide a substrate reaction solution;

measuring the fluorescence of said substrate reaction solution at specified time intervals;

20 adding said solution of HIV protease to an inhibitor-substrate solution comprising a protease inhibitor and said substrate stock solution, to provide an inhibitor-substrate reaction solution;

measuring the fluorescence of said inhibitor-substrate reaction solution at specified time intervals; and

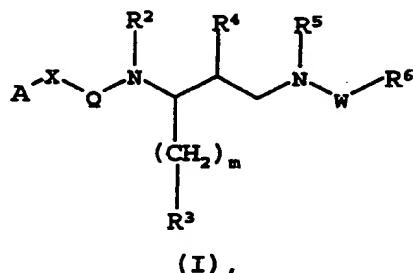
25 calculating the initial velocity of said inhibitor-substrate reaction solution by applying the equation:

$$V = V_0 / 2E_t \left( \{ [K_i(1+S/K_m) + I_t - E_t]^2 + 4K_i(1+S/K_m)E_t \}^{1/2} - [K_i((1+S/K_m) + I_t - E_t)] \right)$$
, wherein V is the initial velocity of said inhibitor reaction solution,  $V_0$  is the initial velocity of said substrate reaction solution,  $K_m$  is the Michaelis-Menten constant, S is the concentration of said substrate,  $E_t$  is

the concentration of said protease, and  $I_t$  is the concentration of said inhibitor, wherein the initial velocities indicates the anti-HIV protease activity of said protease inhibitor.

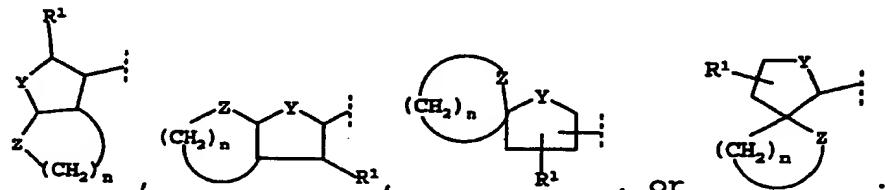
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47. A method of preventing the development of drug resistance in an HIV-infected mammal, said method comprising administering to said HIV-infected mammal a drug resistance-inhibiting effective amount of a compound 10 of the formula:



or a pharmaceutically acceptable salt, a prodrug, or an ester thereof, or a pharmaceutically acceptable 15 composition of said compound, said salt, said prodrug, or said ester thereof, wherein:

A is a group of the formula:



20  $\text{R}^1$  is H or an alkyl, an alkenyl, an alkynyl, a cycloalkyl, a cycloalkylalkyl, an aryl, an aralkyl, a heterocycloalkyl, a heterocycloalkylalkyl, a heteroaryl, or a heteroaralkyl, in which at least one hydrogen atom is optionally substituted with a substituent selected from the group consisting of  $\text{OR}'$ ,  $\text{SR}'$ ,  $\text{CN}$ ,  $\text{NO}_2$ ,  $\text{N}_3$ , and a

halogen, wherein R' is H, an unsubstituted alkyl, an unsubstituted alkenyl, or an unsubstituted alkynyl;

Y and Z are the same or different and are independently selected from the group consisting of  $\text{CH}_2$ ,

5 O, S,  $\text{SO}_2$ ,  $\text{NR}^8$ ,  $\text{R}^8\text{C}(\text{O})\text{N}$ ,  $\text{R}^8\text{C}(\text{S})\text{N}$ ,  $\text{R}^8\text{OC}(\text{O})\text{N}$ ,  $\text{R}^8\text{OC}(\text{S})\text{N}$ ,  $\text{R}^8\text{SC}(\text{O})\text{N}$ ,  $\text{R}^8\text{R}^9\text{NC}(\text{O})\text{N}$ , and  $\text{R}^8\text{R}^9\text{NC}(\text{S})\text{N}$ , wherein  $\text{R}^8$  and  $\text{R}^9$  are each selected from the group consisting of H, an unsubstituted alkyl, an unsubstituted alkenyl, and an unsubstituted alkynyl;

10 n is an integer from 1 to 5;

X is a covalent bond,  $\text{CHR}^{10}$ ,  $\text{CHR}^{10}\text{CH}_2$ ,  $\text{CH}_2\text{CHR}^{10}$ , O,  $\text{NR}^{10}$ , or S, wherein  $\text{R}^{10}$  is H, an unsubstituted alkyl, an unsubstituted alkenyl, or an unsubstituted alkynyl;

Q is  $\text{C}(\text{O})$ ,  $\text{C}(\text{S})$ , or  $\text{SO}_2$ ;

15  $\text{R}^2$  is H, a  $\text{C}_1\text{-C}_6$  alkyl, a  $\text{C}_2\text{-C}_6$  alkenyl, or a  $\text{C}_2\text{-C}_6$  alkynyl;

m is an integer from 0 to 6;

$\text{R}^3$  is a cycloalkyl, a heterocycloalkyl, an aryl, or a heteroaryl in which at least one hydrogen atom is

20 optionally substituted with a substituent selected from the group consisting of alkyl,  $(\text{CH}_2)_p\text{R}^{11}$ ,  $\text{OR}^{12}$ ,  $\text{SR}^{12}$ ,  $\text{CN}$ ,  $\text{N}_3$ ,  $\text{NO}_2$ ,  $\text{NR}^{12}\text{R}^{13}$ ,  $\text{C}(\text{O})\text{R}^{12}$ ,  $\text{C}(\text{S})\text{R}^{12}$ ,  $\text{CO}_2\text{R}^{12}$ ,  $\text{C}(\text{O})\text{SR}^{12}$ ,  $\text{C}(\text{O})\text{NR}^{12}\text{R}^{13}$ ,  $\text{C}(\text{S})\text{NR}^{12}\text{R}^{13}$ ,  $\text{NR}^{12}\text{C}(\text{O})\text{R}^{13}$ ,  $\text{NR}^{12}\text{C}(\text{S})\text{R}^{13}$ ,  $\text{NR}^{12}\text{CO}_2\text{R}^{13}$ ,  $\text{NR}^{12}\text{C}(\text{O})\text{SR}^{13}$ , and a halogen, wherein:

25 p is an integer from 0 to 5;

$\text{R}^{11}$  is a cycloalkyl, a heterocycloalkyl, an aryl, or a heteroaryl in which at least one hydrogen atom is optionally substituted with a substituent selected from the group consisting of a halogen, OH,  $\text{OCH}_3$ ,  $\text{NH}_2$ ,

30  $\text{NO}_2$ , SH, and CN; and

$R^{12}$  and  $R^{13}$  are independently selected from the group consisting of H, an unsubstituted alkyl, an unsubstituted alkenyl, and an unsubstituted alkynyl;

$R^4$  is OH, =O (keto), NH<sub>2</sub>, or NHCH<sub>3</sub>;

5       $R^5$  is H, a C<sub>1</sub>-C<sub>6</sub> alkyl radical, a C<sub>2</sub>-C<sub>6</sub> alkenyl radical, or (CH<sub>2</sub>)<sub>q</sub>R<sup>14</sup>, wherein q is an integer from 0 to 5, and R<sup>14</sup> is a cycloalkyl, a heterocycloalkyl, an aryl, or a heteroaryl radical in which at least one hydrogen atom is optionally substituted with a substituent selected from

10     the group consisting of a halogen, OH, OCH<sub>3</sub>, NH<sub>2</sub>, NO<sub>2</sub>, SH, and CN;

      W is C(O), C(S), or SO<sub>2</sub>; and

      R<sup>6</sup> is a cycloalkyl, heterocycloalkyl, aryl, or heteroaryl radical in which at least one hydrogen atom is

15     optionally substituted with a substituent selected from the group consisting of a halogen, OR<sup>15</sup>, SR<sup>15</sup>, S(O)R<sup>15</sup>, SO<sub>2</sub>R<sup>15</sup>, SO<sub>2</sub>NR<sup>15</sup>R<sup>16</sup>, SO<sub>2</sub>N(OH)R<sup>15</sup>, CN, CR<sup>15</sup>=NR<sup>16</sup>, CR<sup>15</sup>=N(OR<sup>16</sup>), N<sub>3</sub>, NO<sub>2</sub>, NR<sup>15</sup>R<sup>16</sup>, N(OH)R<sup>15</sup>, C(O)R<sup>15</sup>, C(S)R<sup>15</sup>, CO<sub>2</sub>R<sup>15</sup>, C(O)SR<sup>15</sup>, C(O)NR<sup>15</sup>R<sup>16</sup>, C(S)NR<sup>15</sup>R<sup>16</sup>, C(O)N(OH)R<sup>15</sup>, C(S)N(OH)R<sup>15</sup>,

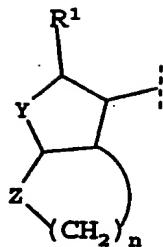
20     NR<sup>15</sup>C(O)R<sup>16</sup>, NR<sup>15</sup>C(S)R<sup>16</sup>, N(OH)C(O)R<sup>15</sup>, N(OH)C(S)R<sup>15</sup>, NR<sup>15</sup>CO<sub>2</sub>R<sup>16</sup>, N(OH)CO<sub>2</sub>R<sup>15</sup>, NR<sup>15</sup>C(O)SR<sup>16</sup>, NR<sup>15</sup>C(O)NR<sup>16</sup>R<sup>17</sup>, NR<sup>15</sup>C(S)NR<sup>16</sup>R<sup>17</sup>, N(OH)C(O)NR<sup>15</sup>R<sup>16</sup>, N(OH)C(S)NR<sup>15</sup>R<sup>16</sup>, NR<sup>15</sup>C(O)N(OH)R<sup>16</sup>, NR<sup>15</sup>C(S)N(OH)R<sup>16</sup>, NR<sup>15</sup>SO<sub>2</sub>R<sup>16</sup>, NHSO<sub>2</sub>NR<sup>15</sup>R<sup>16</sup>, NR<sup>15</sup>SO<sub>2</sub>NHR<sup>16</sup>, P(O)(OR<sup>15</sup>)(OR<sup>16</sup>), an alkyl, an alkoxy, an

25     alkylthio, an alkylamino, a cycloalkyl, a cycloalkylalkyl, a heterocycloalkyl, a heterocycloalkylalkyl, an aryl, an aryloxy, an arylamino, an arylthio, an aralkyl, an aryloxyalkyl, an arylaminoalkyl, an aralkoxy, an (aryloxy)alkoxy, an

30     (arylarnino)alkoxy, an (arylthio)alkoxy, an aralkylamino, an (aryloxy)alkylamino, an (arylarnino)alkylamino, an

(arylthio)alkylamino, an aralkylthio, an  
(aryloxy)alkylthio, an (arylamino)alkylthio, an  
(arylthio)alkylthio, a heteroaryl, a heteroaryloxy, a  
heteroarylarnino, a heteroarylthio, a heteroaralkyl, a  
heteroaralkoxy, a heteroaralkylarnino, and a  
heteroaralkylthio,  
wherein R<sup>15</sup>, R<sup>16</sup>, and R<sup>17</sup> are H, an unsubstituted  
alkyl, or an unsubstituted alkenyl,  
wherein, when at least one hydrogen atom of R<sup>6</sup>  
10 is substituted with a substituent other than a halogen,  
OR<sup>15</sup>, SR<sup>15</sup>, CN, N<sub>3</sub>, NO<sub>2</sub>, NR<sup>15</sup>R<sup>16</sup>, C(O)R<sup>15</sup>, C(S)R<sup>15</sup>, CO<sub>2</sub>R<sup>15</sup>,  
C(O)SR<sup>15</sup>, C(O)NR<sup>15</sup>R<sup>16</sup>, C(S)NR<sup>15</sup>R<sup>16</sup>, NR<sup>15</sup>C(O)R<sup>16</sup>, NR<sup>15</sup>C(S)R<sup>16</sup>,  
NR<sup>15</sup>CO<sub>2</sub>R<sup>16</sup>, NR<sup>15</sup>C(O)SR<sup>16</sup>, NR<sup>15</sup>C(O)NR<sup>16</sup>R<sup>17</sup>, or NR<sup>15</sup>C(S)NR<sup>16</sup>R<sup>17</sup>, at  
least one hydrogen atom on said substituent is optionally  
15 substituted with a halogen, OR<sup>15</sup>, SR<sup>15</sup>, CN, N<sub>3</sub>, NO<sub>2</sub>,  
NR<sup>15</sup>R<sup>16</sup>, C(O)R<sup>15</sup>, C(S)R<sup>15</sup>, CO<sub>2</sub>R<sup>15</sup>, C(O)SR<sup>15</sup>, C(O)NR<sup>15</sup>R<sup>16</sup>,  
C(S)NR<sup>15</sup>R<sup>16</sup>, NR<sup>15</sup>C(O)R<sup>15</sup>, NR<sup>15</sup>C(S)R<sup>16</sup>, NR<sup>15</sup>CO<sub>2</sub>R<sup>16</sup>, NR<sup>15</sup>C(O)SR<sup>16</sup>,  
NR<sup>15</sup>C(O)NR<sup>16</sup>R<sup>17</sup>, or NR<sup>15</sup>C(S)NR<sup>16</sup>R<sup>17</sup>; or  
R<sup>5</sup> and R<sup>6</sup> together with the N-W bond of formula (I)  
20 comprise a 12 to 18 membered ring, comprising at least  
one additional heteroatom in the ring skeleton other than  
the nitrogen of said N-W bond; and  
wherein a mutant virus that is capable of evolving  
from the HIV virus infecting said mammal has lower  
25 fitness, relative to said HIV virus infecting said  
mammal, in the presence of said compound.

48. The method of claim 47, wherein A is a group of  
the formula:



49. The method of claim 47 or 48, wherein:

when  $R^1$  is an alkyl, it is a  $C_1$ - $C_6$  alkyl;

5 when  $R^1$  is an alkenyl it is a  $C_2$ - $C_6$  alkenyl;

when  $R^1$  is a cycloalkyl, a heterocycloalkyl, an aryl, or a heteroaryl,  $R^1$  is a 4-7 membered ring;

when  $R^7$ ,  $R^8$  or  $R^9$  is an unsubstituted alkyl, it is a  $C_1$ - $C_6$  unsubstituted alkyl;

10 when  $R^7$ ,  $R^8$  or  $R^9$  is an unsubstituted alkenyl, it is a  $C_2$ - $C_6$  unsubstituted alkenyl;

$R^3$  is a 4-7 membered ring;

$R^{11}$  is a 4-7 membered ring;

when  $R^{12}$  or  $R^{13}$  is an unsubstituted alkyl, it is a  $C_1$ -

15  $C_6$  unsubstituted alkyl;

when  $R^{12}$  or  $R^{13}$  is an unsubstituted alkenyl, it is a  $C_2$ - $C_6$  unsubstituted alkyl;

when  $R^{14}$  is a cycloalkyl, a heterocycloalkyl, an aryl, or a heteroaryl,  $R^{14}$  is a 4-7 membered ring;

20 when  $R^6$  is a cycloalkyl, a heterocycloalkyl, aryl, or a heteroaryl,  $R^6$  is a 4-7 membered ring;

when  $R^6$  is substituted with a substituent that is an alkyl, an alkylthio, or an alkylamino, the substituent comprises from one to six carbon atoms; and

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when R<sup>6</sup> is substituted with a substituent that is a cycloalkyl, a heterocycloalkyl, an aryl, or a heteroaryl, the substituent is a 4-7 membered ring;

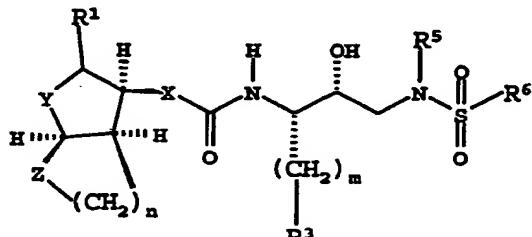
or a pharmaceutically acceptable salt, a prodrug, or

5 an ester thereof.

50. The method of any one of claims 47-49, wherein Q is C(O), R<sup>2</sup> is H, and W is SO<sub>2</sub>, or a pharmaceutically acceptable salt, a prodrug, or an ester thereof.

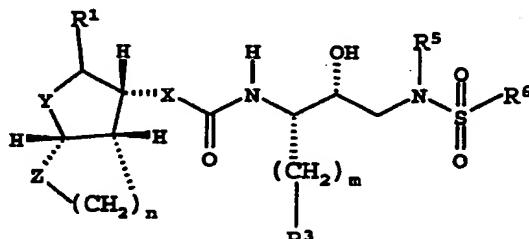
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51. The method of claim 48, wherein said compound is represented by the formula:



or

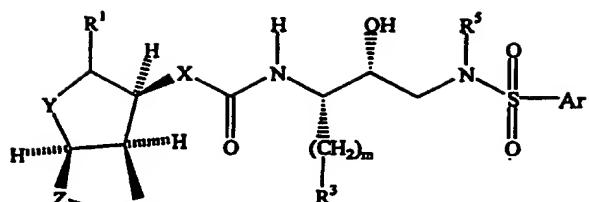
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52. The method of claim 51, wherein said compound

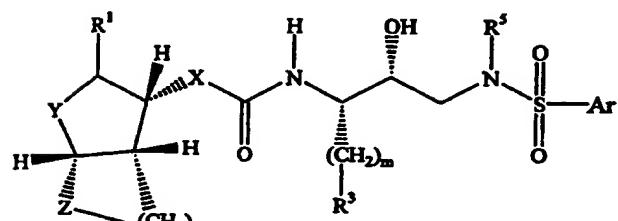
20 is represented by the formula:

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(IC)

or

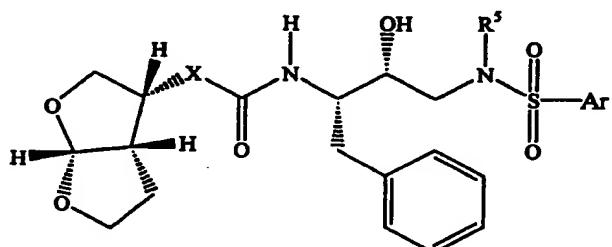


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(ID),

wherein Ar is a phenyl which is optionally substituted with a substituent selected from the group consisting of methyl, amino, hydroxy, methoxy, methylthio, hydroxymethyl, aminomethyl, and methoxymethyl.

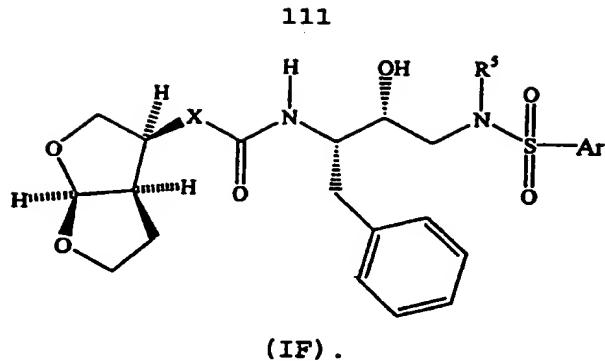
53. The method of claim 52, wherein said compound is represented by the formula:



15

(IE)

or



54. The method of claim 52 or 53, wherein X is  
5 oxygen.

55. The method of claim 52 or 53, wherein R<sup>5</sup> is  
isobutyl.

10 56. The method of claim 52 or 53, wherein Ar is a  
phenyl substituted at the para-position.

57. The method of claim 52 or 53, wherein Ar is a  
phenyl substituted at the meta-position.

15 58. The method of claim 52 or 53, wherein Ar is a  
phenyl substituted at the ortho-position.

59. The method of claim 52 or 53, wherein Ar is  
20 selected from the group consisting of para-aminophenyl,  
para-tolyl, para-methoxyphenyl, meta-methoxyphenyl, and  
meta-hydroxymethylphenyl.

60. The method of any one of claims 47, 48, or 51-  
25 53, wherein said HIV-infected mammal is infected with a  
wild-type HIV.

61. The method of any one of claims 47, 48, or 51-53, wherein said HIV-infected mammal is infected by a mutant HIV with least one protease mutation.

5

62. The method of any one of claims 47, 48, or 51-53, wherein said HIV-infected mammal is infected by a mutant HIV having at least one reverse transcriptase mutation.

10

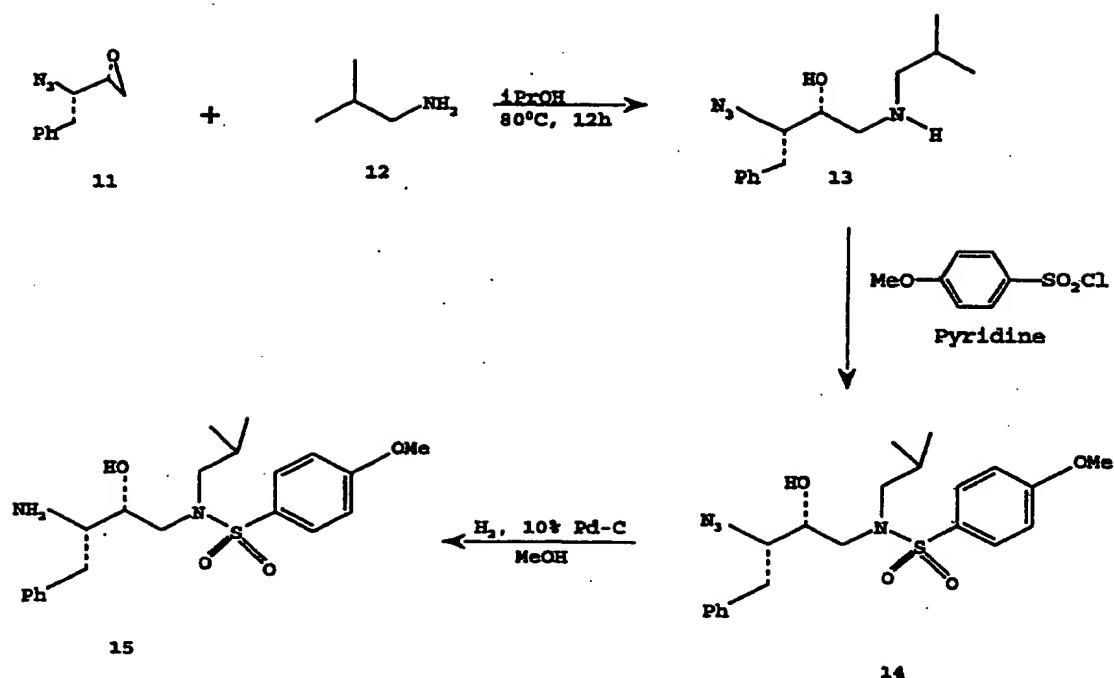


Fig. 1

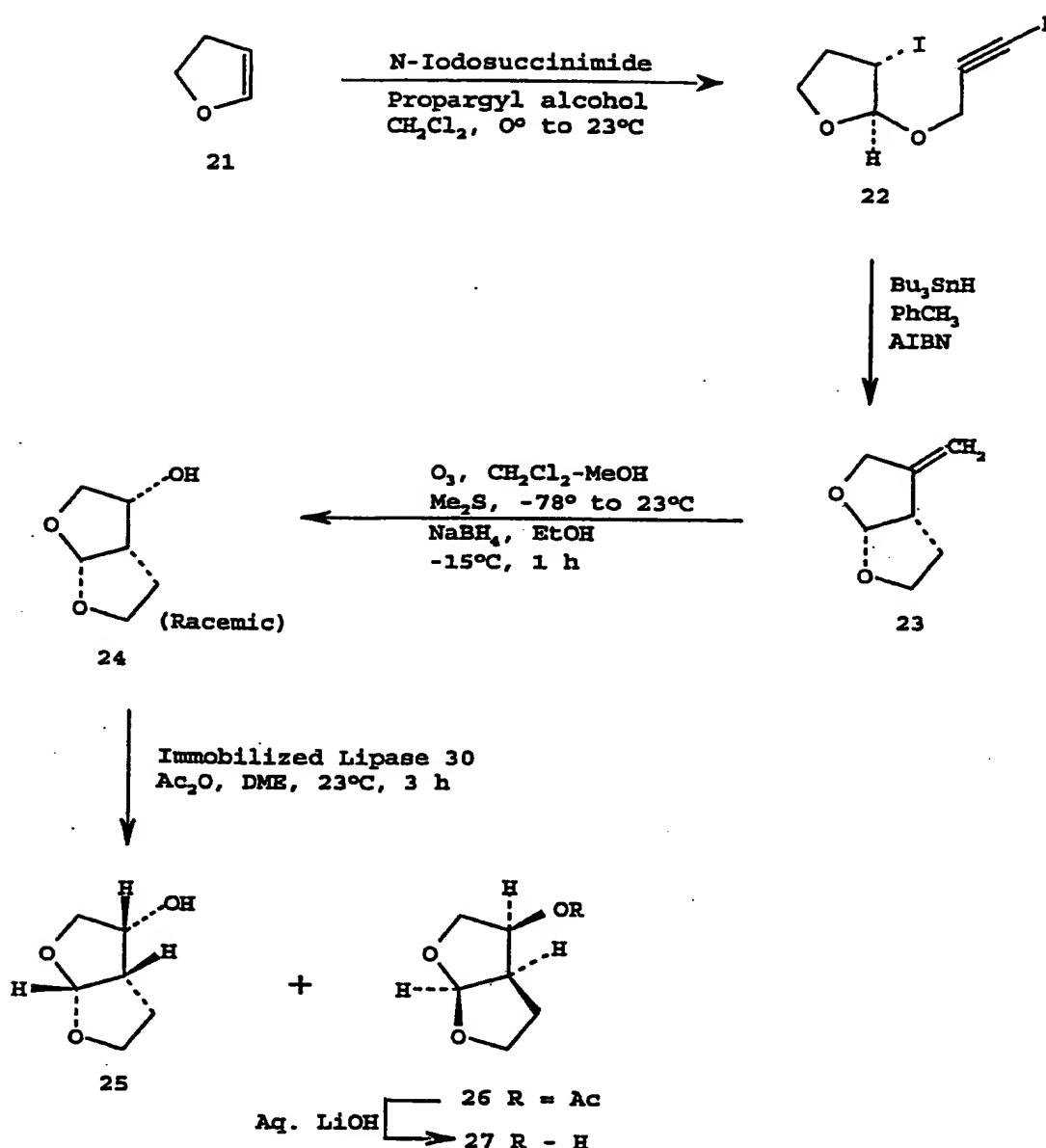


Fig. 2

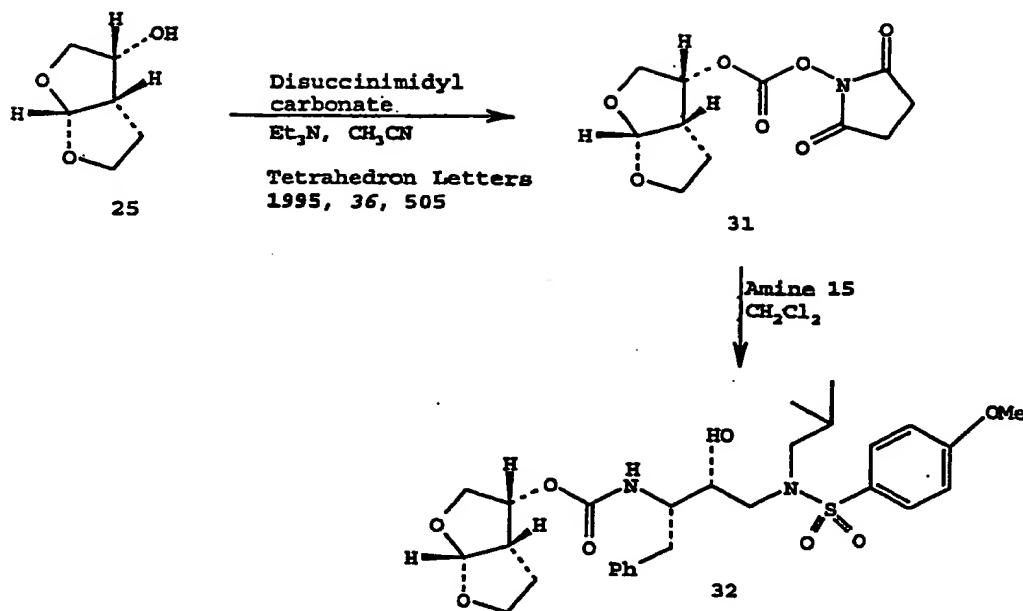


Fig. 3A

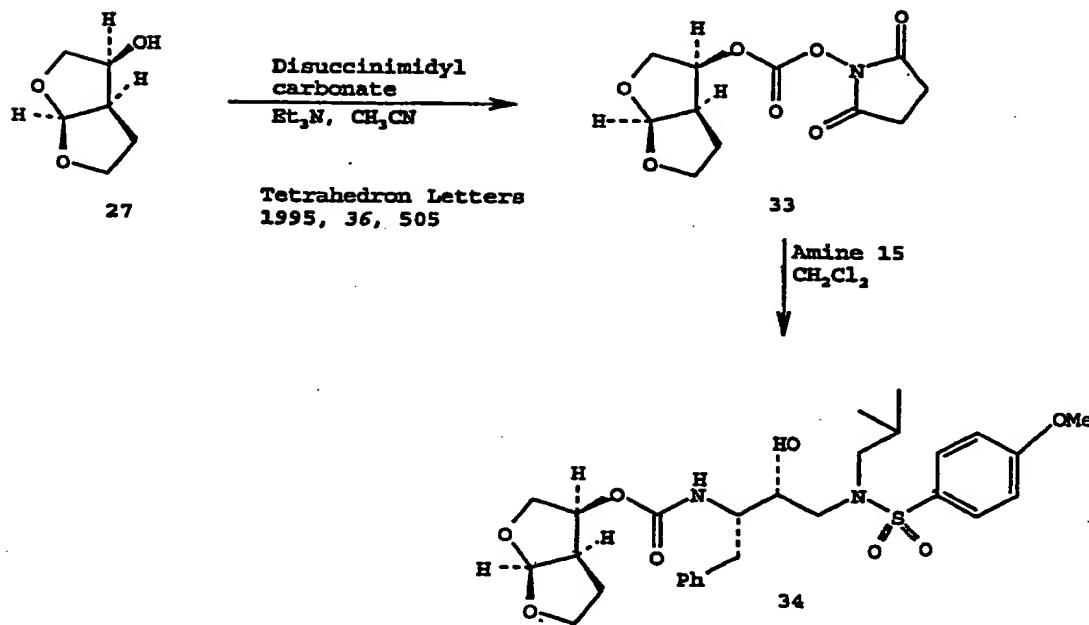


Fig. 3B

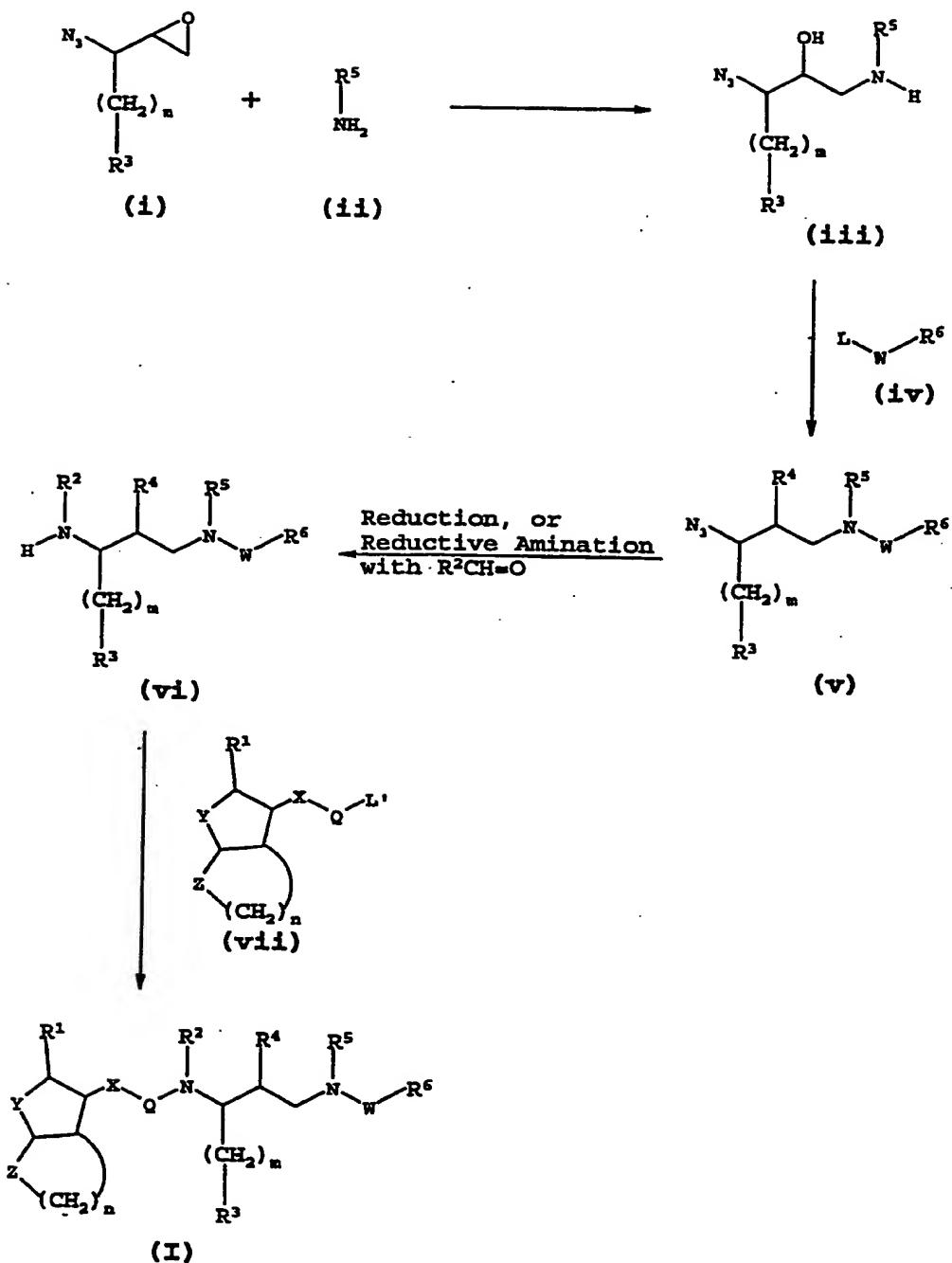
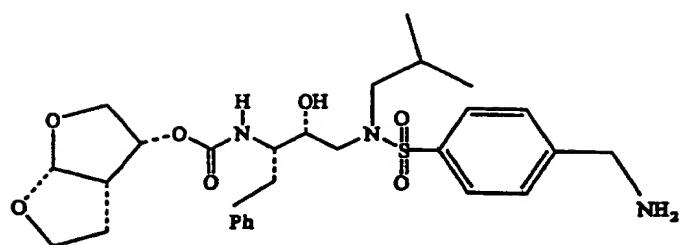
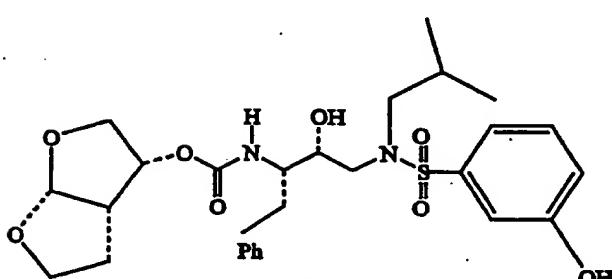


Fig. 4



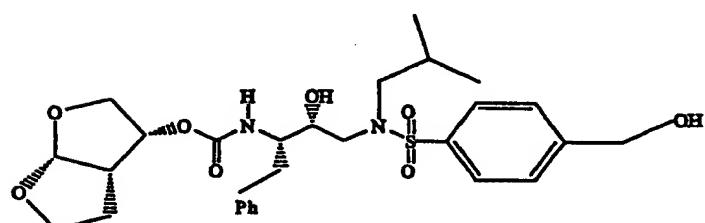
35

Fig. 5A



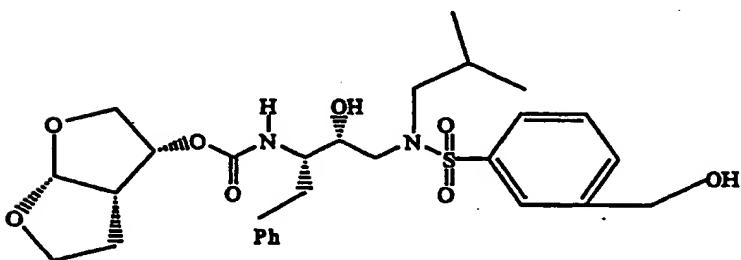
36

Fig. 5B



37

Fig. 5C



38

Fig. 5D